Seventh Quarterly Report

DEVELOPMENT OF UNIFORM AND PREDICTABLE BATTERY MATERIALS FOR NICKEL-CADMIUM AEROSPACE CELLS

8 March 1970 — 7 June 1970

Contract No. NAS 5-11561

Prepared by

Tyco Laboratories, Inc.

Bear Hill

Waltham, Massachusetts 02154

for

Goddard Space Flight Center

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ABSTRACT

This report describes studies of the impregnation of nickel plaque to form nickel cadmium battery plates. Two basic processes were examined: (1) chemical conversion of the nitrates to the hydroxides, and (2) the method first described by Fleischer. The aim was to define the procedures and preparative conditions that would give rise to the most uniform components in a reproducible manner.

The variables considered were solution concentration for chemical conversion, current density for the Fleischer method, and the loading for both methods. These variables were chosen for more detailed study from a previous preliminary examination of impregnation methods. The plates were examined in terms of uniformity and reproducibility of weight gain, capacity, and utilization. The determination of utilization demanded chemical analysis of the active materials.

It was concluded from the experimental data collected that more uniform and reproducible plates were prepared by the chemical conversion process. For the positive plates, the less concentrated impregnation solution are to be preferred. No distinction could be drawn for the negatives. It should be stressed that this is an interim assessment based on capacities measured after up to ten cycles and has not included factors such as cycle life or behavior under sealed cell conditions.

It is also apparent from the data that uniformity and reproducibility of weight gain and capacity improve with loading, suggesting that there is a leveling effect (as might be expected). More surprisingly, utilization was found to be independent of loading up to quite high levels. From a limited amount of data, plaque thickness was found to have no influence on uniformity. Plaque corrosion during impregnation was more extensive for the chemical conversion process.

Future work will include an assessment of electrochemical methods of impregnation and a study of plaque and plate preparative conditions on cycle life and sealed cell behavior.

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I. INTRODUCTION

The aim of this program is the definition of a systematic procedure for producing uniform components for nickel cadmium cells. The first phase (described in earlier reports)[1] emphasized the production of uniform porous nickel plaque both in loose sintering and a slurry coating process, and the development of experimental techniques to identify uniform physical characteristics. The second phase involves a study of the factors considered important in the impregnation of plaque with active materials to produce battery plates.

The basic approach in the impregnation process is to precipitate the hydroxides of cadmium or nickel in the pore structure of the nickel plaque. Several methods are available for this process. These are:

1. Chemical conversion of the nitrate to the hydroxide in KOH
2. Chemical conversion of the nitrate to the hydroxide with simultaneous cathodization in KOH
3. Partial thermal decomposition of the nitrate followed by chemical conversion in KOH
4. Cathodization in solutions of the nitrates.

The first three are basically similar and involve vacuum impregnation with nickel or cadmium nitrate solution in the presence of nitric acid as the initial step. They differ only in the process by which the nitrates are converted into the hydroxides. The last method relies on electrochemical conversion by cathodization.

In the method described by Fleischer,[2] the plaque, after impregnation with a near-saturated solution of the nitrate, is immersed immediately in KOH with simultaneous cathodization. The influence of cathodization is to reduce the nitrate ions and thereby increase the pH of the solution deep in the pore structure and precipitate the hydroxide more efficiently. Cathodization also removes the nitrate ions which, if occluded in the active mass, could contribute to self-discharge in cells subsequently

fabricated from these plates. The process is repeated as many times as necessary (usually four to five times) to obtain the desired weight gain and capacity.

Cathodization is not essential if, after impregnation, the plaques are dried prior to immersion in the hot KOH. This method of chemical conversion is one of the preferred methods in commercial plate fabrication. A further variant, first described by Casey, et al.,[3] involves partial thermal decomposition of the nitrates at approximately 200 °C prior to immersion in KOH. For this process, the plaques are impregnated with nitrate salt dissolved in its own water of crystallization by heating. This process has the advantage that fewer impregnation cycles are required. The specific capacity is quite dependent on the temperature of the thermal decomposition.

This report describes the degree of uniformity and reproducibility of plates prepared by both chemical conversion and by the Fleischer method. Preparative conditions and loading with active material were varied, and the plates were assessed in terms of the uniformity and reproducibility of weight gain/unit area, capacity, and utilization.

II. EXPERIMENTAL

A. Program

A preliminary examination of the experimental variables associated with the impregnation of nickel cadmium battery plates by chemical conversion and by the Fleischer method was presented in a previous report.[4] On the basis of this previous work, we were able to limit the number of variables in the more detailed study described here and to restrict the range in which the chosen variables were examined. For example, no variation in solution concentrations nor in temperature were considered for the Fleischer method. All the chemical conversion processes were carried out at 80 °C. The experimental program set out in summary in Table I had the objective of defining the uniformity and reproducibility of:

1. Weight gain/unit area
2. Capacity and utilization of active materials on cycling
3. The extent of plaque corrosion.

as a function of the preparative conditions and loading of the active material. The preparative conditions are considered to control the morphology of the active material which in turn will affect utilization. The loading with active materials and their distribution in the porous mass are also of obvious factors to consider in defining utilization.

B. Impregnation Procedures

The basic methods of plaque impregnation have been described previously but will be repeated here for completeness.

1. Fleischer process

The equipment used for the impregnation process is shown in Fig. 1. It consists of an impregnation tank and reservoir for the impregnation solution. The

Table I. Program of Plate Preparations

A. Fleischer Method

Positives (PF series)	saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C
	—2,5,8, and 12 impregnation cycles, cathodized at 150 mA/cm^2
	—2, 5, 8, and 12 impregnation cycles, cathodized at 300 mA/cm^2
Negatives (NF series)	saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C
	—2, 5, 8, and 12 impregnation cycles, cathodized at 150 mA/cm^2
	—2, 5, 8, and 12 impregnation cycles, cathodized at 300 mA/cm^2

B. Chemical Conversion

Positives (PC series)	saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C
	—2, 5, 8, and 12 impregnation cycles
	50% saturated $Ni(NO_3)_2$ + nitric acid, 10% KOH at 80 °C
	—2, 5, 8, and 12 impregnation cycles
Negatives (NC series)	saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C
	—2, 5, 8, and 12 impregnation cycles
	50% saturated $Cd(NO_3)_2$ + nitric acid, 10% KOH at 80 °C
	—2, 5, 8, and 12 impregnation cycles

C. Modified Fleischer Method

Positives (PC series)	saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C
	—2, 5, and 8 impregnation cycles, dried at 80 °C, cathodized at 150 mA/cm^2.

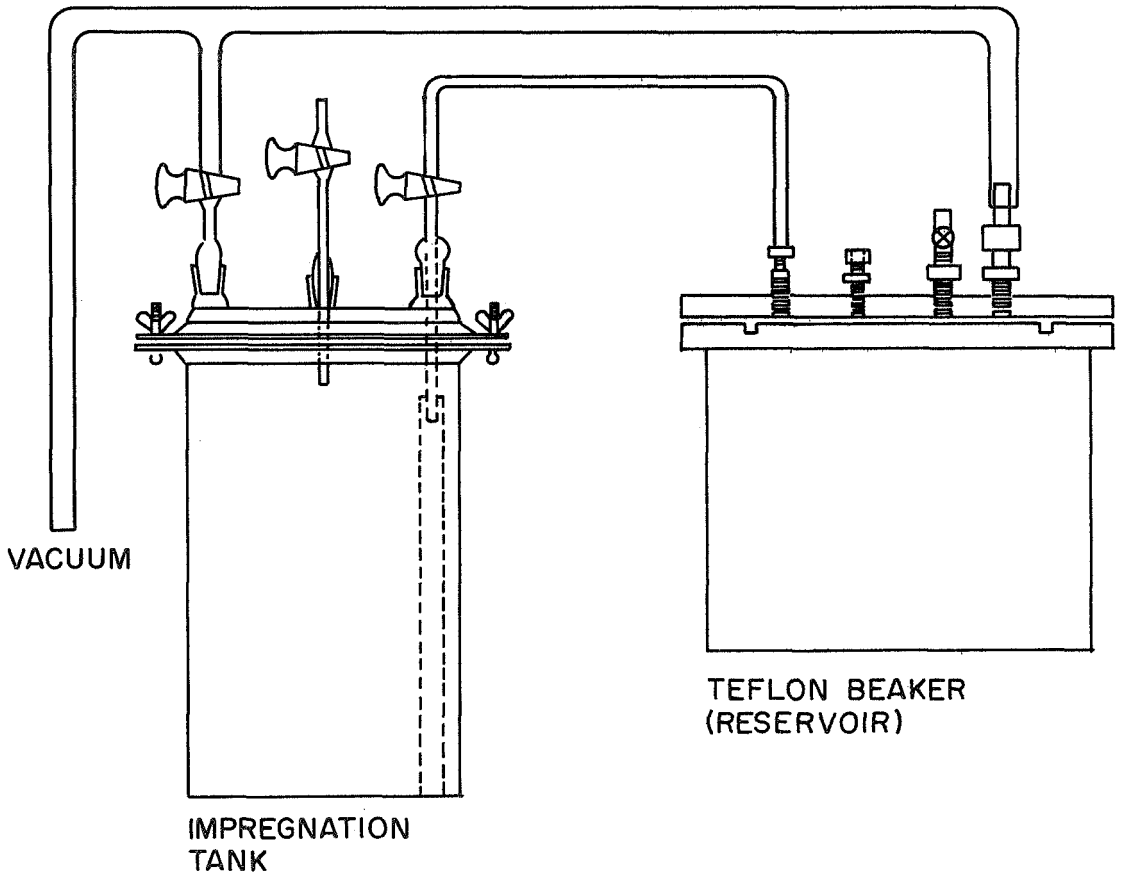

Fig. 1. Vacuum impregnation apparatus

vacuum lines permit the transfer of the impregnation solution to and from the impregnation tank. The plaques were mounted on a terminal post at the commencement of the process and inserted in the impregnation tank. The jar was evacuated for 5 min before the impregnation solution was drawn in. The tank was then opened to atmospheric pressure. After a 5-min soak period, the plaque was transferred directly into the KOH solution. The terminal post was inserted into a sleeve in the lid of the KOH bath and the necessary cell connections made before immersion. The KOH solution was open to the atmosphere only during the immersion of the electrode. At all other times, the surface of the solution was blanketed with N_2 to prevent carbonate buildup. After immersion in KOH for 20 min, the plaque was removed into a beaker of distilled water. Subsequently, the plates were thoroughly washed by forcing distilled water through the plaque until the wash water in contact with the plate had a pH less than 8.0. No loss of active material was observed in this process, but if any losses did occur, we may assume that it was loosely adherent material that might not cycle efficiently. The plate was then dried and weighed and the whole process repeated. The basic conditions for this process were near-saturated nickel nitrate, 1534.6 g $Ni(OH_3)_2 \cdot 6H_2O$ dissolved in 465.4 ml water with 4 ml of 70% nitric acid, 25% KOH at 80 °C, with a cathodization current of 150 mA/cm^2.

For negative plates, the basic solution was made up from 1456 g of $Cd(NO_3)_2 \cdot 4H_2O$ in 544 ml of water with 4 ml of 70% nitric acid.

2. Chemical conversion

The chemical conversion of the nitrates to the hydroxides was carried out in almost identical fashion to the Fleischer process. The main difference was that, after vacuum impregnation with the nitrates, the plaques were dried for 2 to 3 hr at 80 °C. They were then immersed in the hot KOH without cathodization. Solution compositions were as defined for the Fleischer process.

3. Modified Fleischer approach

A limited number of preparations were carried out in which the drying step of the chemical conversion approach was included in the Fleischer Method. The drying conditions were 2 to 3 hr at 80 °C.

C. Plate Characterization

1. Weight distribution of active materials

The 5 × 2 1/2-in. plates were cut into three pieces of approximately

equal size 1 2/3 × 2 1/2 in. The areas were determined by projection onto squared paper, and the weight of each piece of plate measured. In the following presentation of the results, the pieces are labelled A, B, and C; with the top piece, i.e., the nearest to the current collecting tab in the Fleischer process, being piece A.

2. Capacity measurements

Capacity measurements were made on a section of piece A, approximately 1 1/2 × 1 1/2 in., the remainder of the piece being used for chemical analysis in the green state. Capacities were determined in flooded cells with oversize counter electrodes. Both charge and discharge were carried out at the C/2 rate (i.e., a rate at which the plate would be discharged in half an hour). To prevent overdischarge, particularly of the negative plates, discharge was carried out to a 1 V cutoff. Each plate received 100% overcharge based on the C/2 rate. The plates were cycled until three consecutive cycles gave concordant values. This was usually achieved within six cycles for the positives and six to eight cycles for the negatives.

3. Chemical analysis

The procedures for chemical analysis have been previously[5] defined and are too elaborate to reproduce in detail. The negative plates prepared by the Fleischer method were examined in the green state (prior to cycling) to determine the relative quantities of cadmium and cadmium hydroxide. (Calcium is produced from cadmium hydroxide in the impregnation process during cathodization though the conversion is not complete.) This determination is essential to define the total quantity of cadmium in the plate in order to calculate the utilization of the active material of cycling.

The positive plates were analyzed in the green state and in the discharge state after cycling for the quantity of active material, its water content, and the extent of plaque corrosion.

BET surface areas were measured using an Engelhard Isorpta for selected positive plates.

D. Experimental Data

The plate preparations carried out are defined in Table I. Complete details of the experimental measurements are presented in data sheets in Appendix I. The code letters used are as follows:

P - Positive

N - Negative

F - Fleischer method

C - Chemical conversion

The letters a and b are used to denote the duplicate preparations made in each case. Thus, the code PC1a represents the first preparation of a positive plate by chemical conversion according to the details set out in the data sheet. PC1b represents the duplicate preparation. The modified Fleischer approach for the preparation of positive plates, in which the drying step of the chemical conversion process is included, is denoted as PCF.

III. DISCUSSION

A. Fleischer Method - Positive Plates

A summary of the positive plate impregnation data by the Fleischer method is given in Table II. Plates were prepared in duplicate with 2, 5, 8 and 12 impregnations. The first series PF1 through PF4 was cathodized at 300 mA/cm^2. Considering the weight gain first, reproducibility from preparation to preparation was reasonable. Little distinction can be made from these data between the reproducibility at 150 mA/cm^2 and at 300 mA/cm^2. In general, there is better reproducibility for the A pieces (i.e., closest to the point of current takeoff). In addition to the final weight gains listed, we may also assess reproducibility by comparing the weight gains for the whole plate at the end of each impregnation cycle for each plate preparation, e.g., we may compare the first five impregnations of PF3 with the five impregnations of PF2. The data for PF1 through PF4 arepresented in Fig. 2. The abscissae are offset to permit separate identification of the curves. Good reproducibility is indicated by a horizontal line through equivalent points of the different curves. It is apparent that very good reproducibility is obtained in the first four cycles, that we begin to see some deviation at the fifth cycle and that quite considerable variation is observed for a greater number of cycles. However, for those plates cathodized at 300 mA/cm^2, much better reproducibility is observed for the larger number of impregnations (Fig. 3).

The theoretical capacities listed in Table II were derived from the amount of active material present in the plates, determined as $Ni(OH)_2$ by chemical analysis. Since the water content of the active material is found to vary from preparation to preparation (see below), these theoretical capacities for plates PF1 through PF4 show an anomaly in that the value for PF4 is less than that of PF3. It would appear that the preparative conditions for PF4 were different from the rest of the series. This factor was also apparent in the analysis of reproducibility. The same trend was

Table II. Capacity, Weight-Gain and Utilization – Fleischer Method, Positive Plates

	Impregnations	Active Material, g/cm^2 A	B	C	Capacity, Ahr/cm^3 Theoretical*	Measured†	Utilization, %
150 mA/cm^2							
PF1a	2	0.0353	0.0348	0.0306	0.163	0.111	68
b		0.0351	0.0350	0.0331			
PF2a	5	0.0709	0.0696	0.0640	0.247	0.199	81
b		0.0680	0.0660	0.0672			
PF3a	8	0.0889	0.0956	0.0871	0.312	0.347	110
b		0.0887	0.0927	0.0823		0.330	
PF4a	12	0.0921	0.0885	0.0913	0.281	0.315	112
b		0.0919	0.0951	0.0968		0.315	
300 mA/cm^2							
PF5a	2	0.0351	0.0358	0.0309	0.119	0.111	94
b		0.0308	0.0307	0.0289			
PF6a	5	0.0671	0.0728	0.0672	0.248	0.221	86
b		0.0714	0.0643	0.0635		0.241	
PF7a	8	0.0923	0.0928	0.0909	0.326	0.298	91
b		0.0936	0.0927	0.0936		(0.338)	
PF8a	12	0.1129	0.1035	0.1111	0.898	0.347	87
b		0.1088	0.1145	0.1112			

*Based on chemical analysis for $Ni(OH)_2$ and a 1e charge discharge process.

†Measured on piece A.

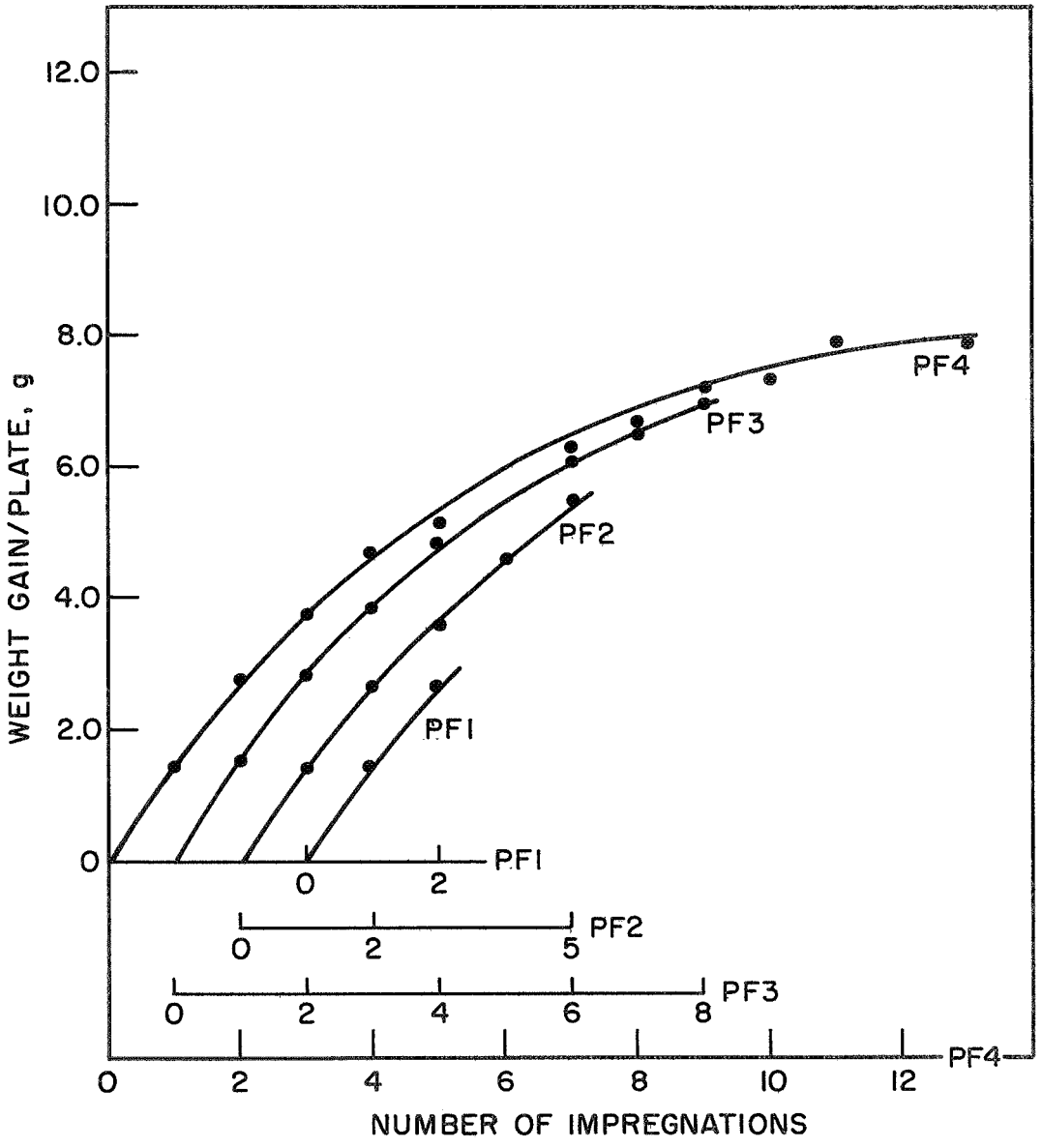

Fig. 2. Reproducibility of Fleischer impregnation process – positive plates cathodized at 150 mA/cm^2

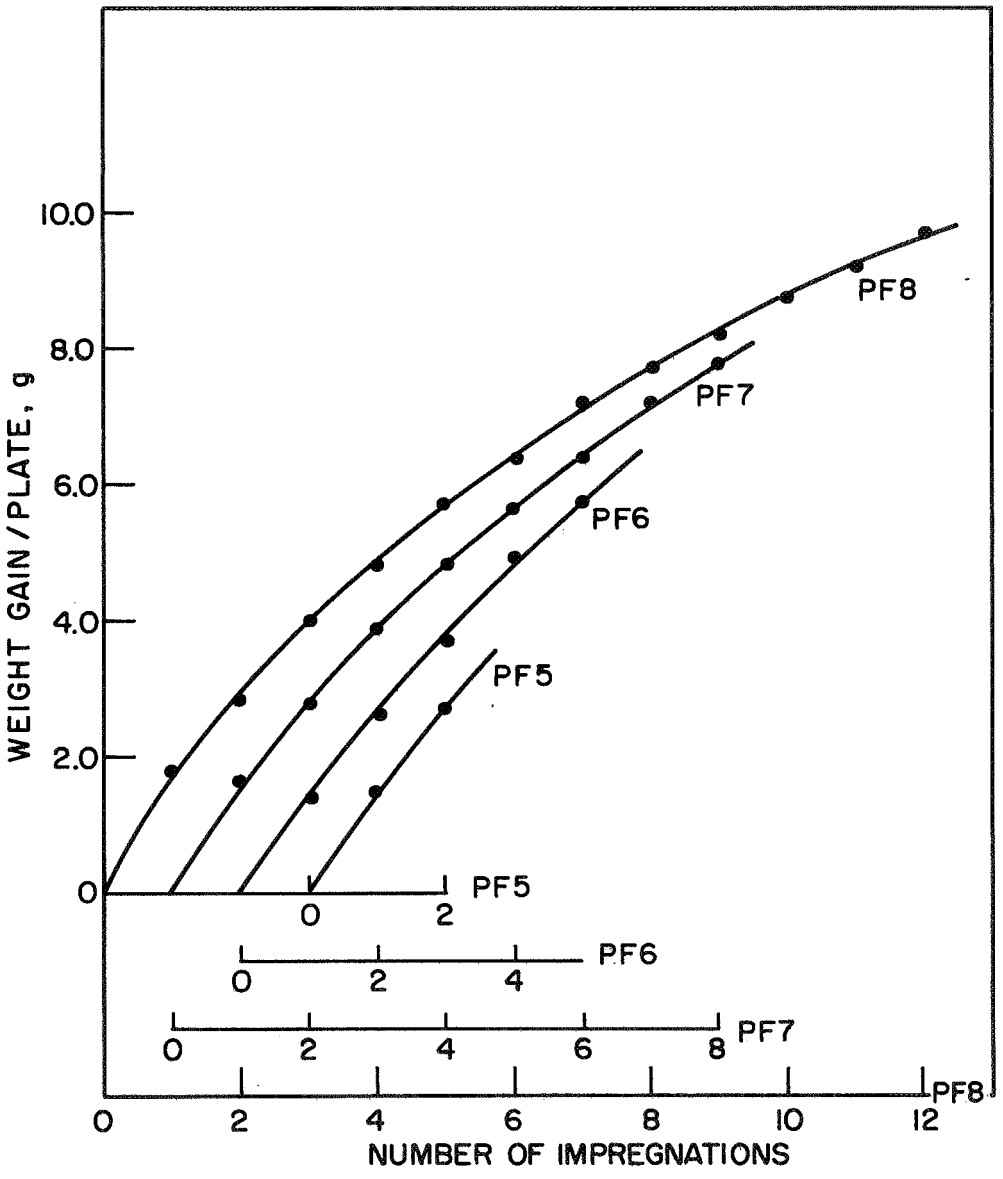

Fig. 3. Reproducibility of Fleischer impregnation process – positive plates cathodized at 300 mA/cm^3

noted in the measured capacities. The capacity of PF3 of 0.35 Ahr/cm^3 is typical of that for plates used in battery manufacture. The number of cycles to achieve this capacity, however, is greater than that normally required in commercial practice probably because the extent of plaque corrosion (the corrosion product becomes positive active material) is a lot less in the preparations considered here. An interesting feature of these results is that the utilization of the active material is independent of the loading. From the figures presented in Table II, the utilization at 90% is apparently better in the more heavily loaded plaques.

Plates PF5 through PF8 show a consistent increase in capacity and the same high utilization independent of loading noted above. The measured capacities are slightly higher than the plates cathodized at 150 mA/cm^2.

B. Chemical Conversion - Positive Plates

The data collected for positive plates prepared by chemical conversion are presented in Table III. Reproducibility of weight gain between the duplicate preparations was slightly better than the plates prepared by the Fleischer method. In comparing the weight gain per impregnation cycle (Figs. 4 and 5) it may be noted that the plates prepared with the less concentrated impregnation solutions showed much better reproducibility. For the saturated impregnation solution, plate PC3 shows quite different characteristics from the rest of the group. The scatter in the remainder is slightly greater than that observed in the Fleischer process.

Uniformity of weight gain in a particular plate for the chemical conversion process proved to be better than that of the Fleischer method. No pattern in weight distribution could be observed, and the uniformity improved with increasing number of impregnation cycles. For the most part, the spread in distribution was within 4%. In the better examples, the deviation from the mean value is less than ± 1%.

Theoretical capacities were based on chemical analysis of the plates. For these plates the pattern of capacity and weight gain did not show the anomalies observed for the Fleischer process. Measured capacities were quite reproducible for the replicate plates. For the same number of impregnations, the capacities were higher than the comparable number for the Fleischer process. This is due to the greater corrosion of the plaque that probably takes place during the drying of the plate after impregnation with the nickel nitrate-nitric acid solution. This fact is confirmed in the chemical analyses presented in the Appendix, and is discussed in more detail later.

Table III. Capacity, Weight-Gain and Utilization – Chemical Conversion, Positive Plates

	Number of Impregnations	Active Material, g/cm^2			Capacity, Ahr/cm^3		Utilization, %
		A	B	C	Theoretical	Measured*	
Saturated $Ni(NO_3)_2$							
PC1a	2	0.0529	0.0485	0.0504	0.141	0.173	122
b		0.0469	0.0501	0.0545		0.166	
PC2a	5	0.0984	0.0944	0.1011	0.328	0.314	91
b		0.0976	0.0914	0.0943		0.340	
PC3a	8	0.1282	0.1235	0.1250	0.457	0.452	99
b		0.1286	0.1284	0.1268		0.445	
PC4a	12	0.1523	0.1564	0.1479	0.583	0.491	84
b		0.1562	0.1542	0.1529			
50% Saturated $Ni(NO_3)_2$							
PC5a	2	0.0150	0.0155	0.0155	0.046	0.047	102
PC6a	5	0.0311	0.0351	0.0347	0.096	0.087	91
PC7a	8	0.0506	0.0484	0.0494	0.188	0.181	96
PC8a	12	0.0747	0.0730	0.0734	0.246	0.261	106

*Measured on piece A.

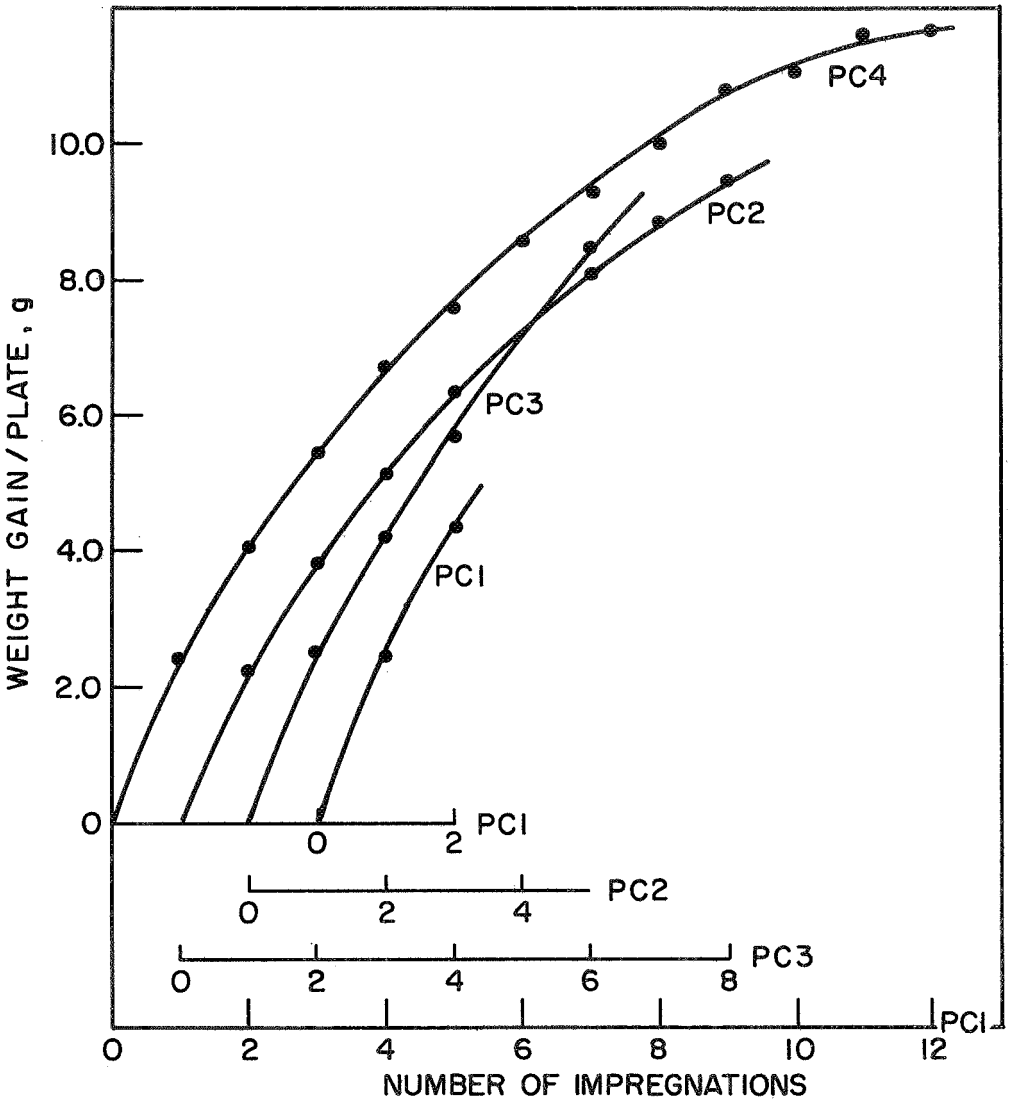

Fig. 4. Reproducibility of chemical conversion process – positive plates saturated impregnation solution

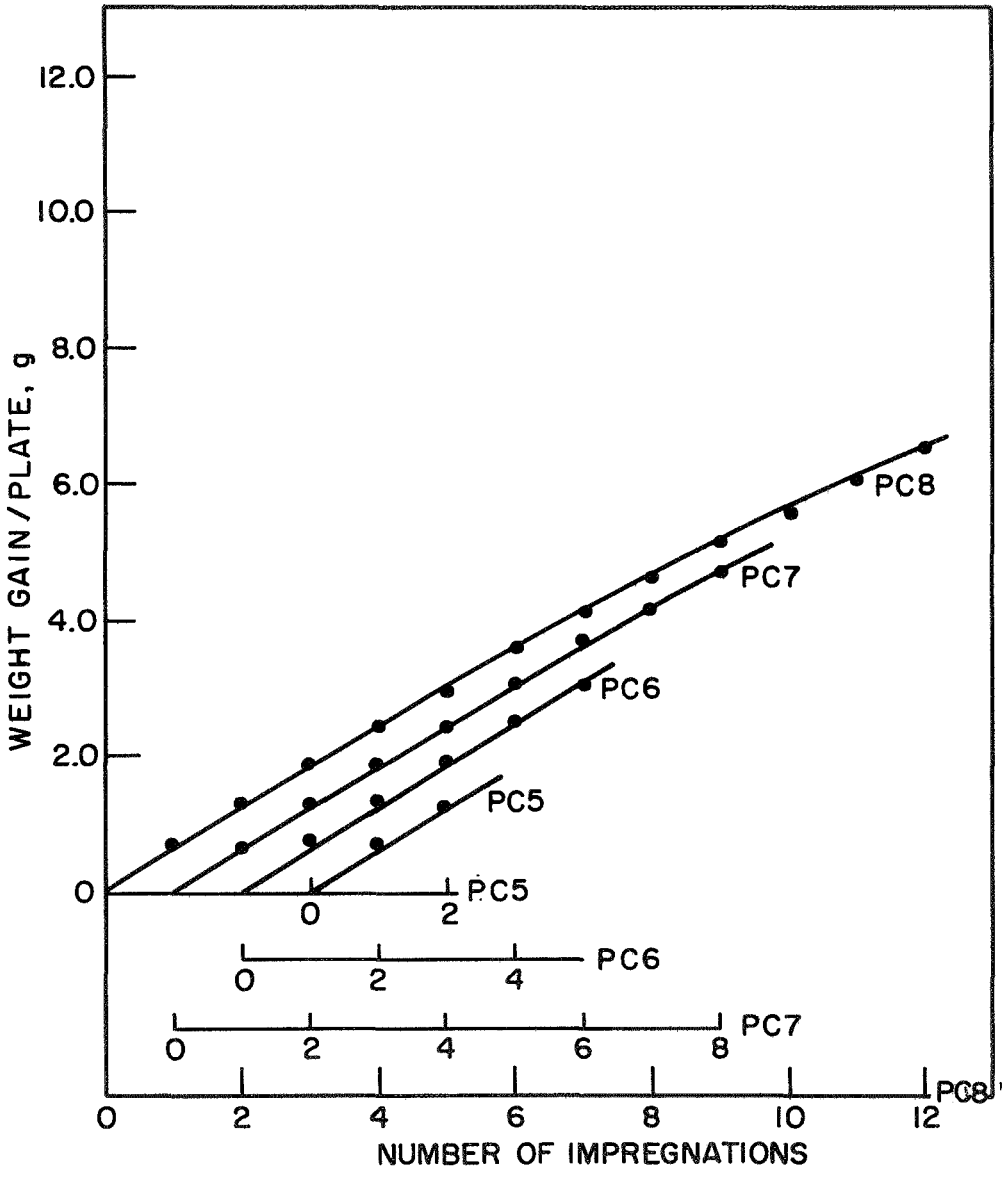

Fig. 5. Reproducibility of chemical conversion process – positive plates, 50% saturated impregnation solution

Utilization of the active materials is again independent of loading, though it is somewhat lower for PC4. Note that utilization figures can be greater than 100% since they are based on a 1 electron transfer per Ni atom in the active material. Since the charged state is nonstoichiometric, with an apparent valence greater than three the actual valence change during charge and discharge can be greater than one.

Though impregnation with the less concentrated solutions is attractive from a uniformity and reproducibility point of view, the specific capacity even after twelve impregnations is less than that normally used in practical cells.

C. Fleischer Method - Negatives

A summary of the data on negative plates prepared by the Fleischer process is given in Table IV. Plates NF1 through NF4 were cathodized at 150 mA/cm^2 and plates NF5 through NF8 at 300 mA/cm^2. Reasonable reproducibility was obtained in the duplicate preparations in most cases, the largest differences being observed in the low loading plates. These figures must, however, be regarded more circumspectly than those for the positive plates, since in these preparations the cathodic current can, in addition to reducing nitrate, convert cadmium hydroxide to cadmium. Thus, the active material in the green plate is a mixture of cadmium and cadmium hydroxide, the relative proportions in different areas of the plate being dependent on the current distribution across the plate. Under these circumstances, it is to be expected that there would be greater disparity between the figures for the 300 mA/cm^2 preparations than those for the preparations at 150 mA/cm^2. This is not apparent from the figures in Table IV but if we examine the reproducibility in terms of the weight gain per impregnation cycle (Figs. 6 and 7) we note that at 150 mA/cm^2 there is more scatter than was observed for the positives and at 300 mA/cm^2 considerable variations in weight gain are noted.

Because of the distribution of current density during cathodization it is not possible to assess the uniformity of the distribution of active material throughout a particular plate from the figures presented in Table IV. However, chemical analyses were carried out on Sections A and C of plates NF1 to NF4 to determine the relative amounts of cadmium and cadmium hydroxide. These figures were then converted to give a value for the weight of cadmium per unit area in each section. The results derived from the chemical analyses described in the Appendix are presented in Table V. As will be noted, excellent agreement with one exception is obtained in

Table IV. Capacity, Weight-Gain and Utilization – Fleischer Method, Negative Plates

	Number of Impregnations	Active Material, g/cm^3			Capacity Ahr/cm^3		Utilization, %
		A	B	C	Theoretical	Measured*	
150 mA/cm^2							
NF1a	2	0.0469	0.0649	0.0524	0.304	0.207	68
b		0.0497	0.0459	0.0516	0.275	0.212	77
NF2a	5	0.1337	0.1259	0.1208	0.658	0.492	75
b		0.1255	0.1353	0.1270	0.677	0.461	69
NF3a	8	0.1662	0.1699	0.1632	0.808	0.590	74
b		0.1703	0.1673	0.1642	0.790	0.610	77
NF4a	12	0.2018	0.2121	0.1928	0.956	0.726	76
b		0.2230	0.1943	0.1904	0.922	0.663	72
300 mA/cm^2							
NF5a	2	0.0430	0.0664	0.0682	0.279	0.213	76
b		0.0530	0.0545	0.0572	0.343	0.233	68
NF6a	5	0.1162	0.1198	0.1360	0.601	0.474	79
b		0.1127	0.1159	0.1115	0.725	0.426	60
NF7a	8	0.1563	0.1563	0.1635	0.823	0.593	72
b		0.1533	0.1508	0.1512			
NF8a	12	0.1807	0.1915	0.2006	1.179	0.576	49
b		0.2042	0.2162	0.2069			

*Measured on piece A.

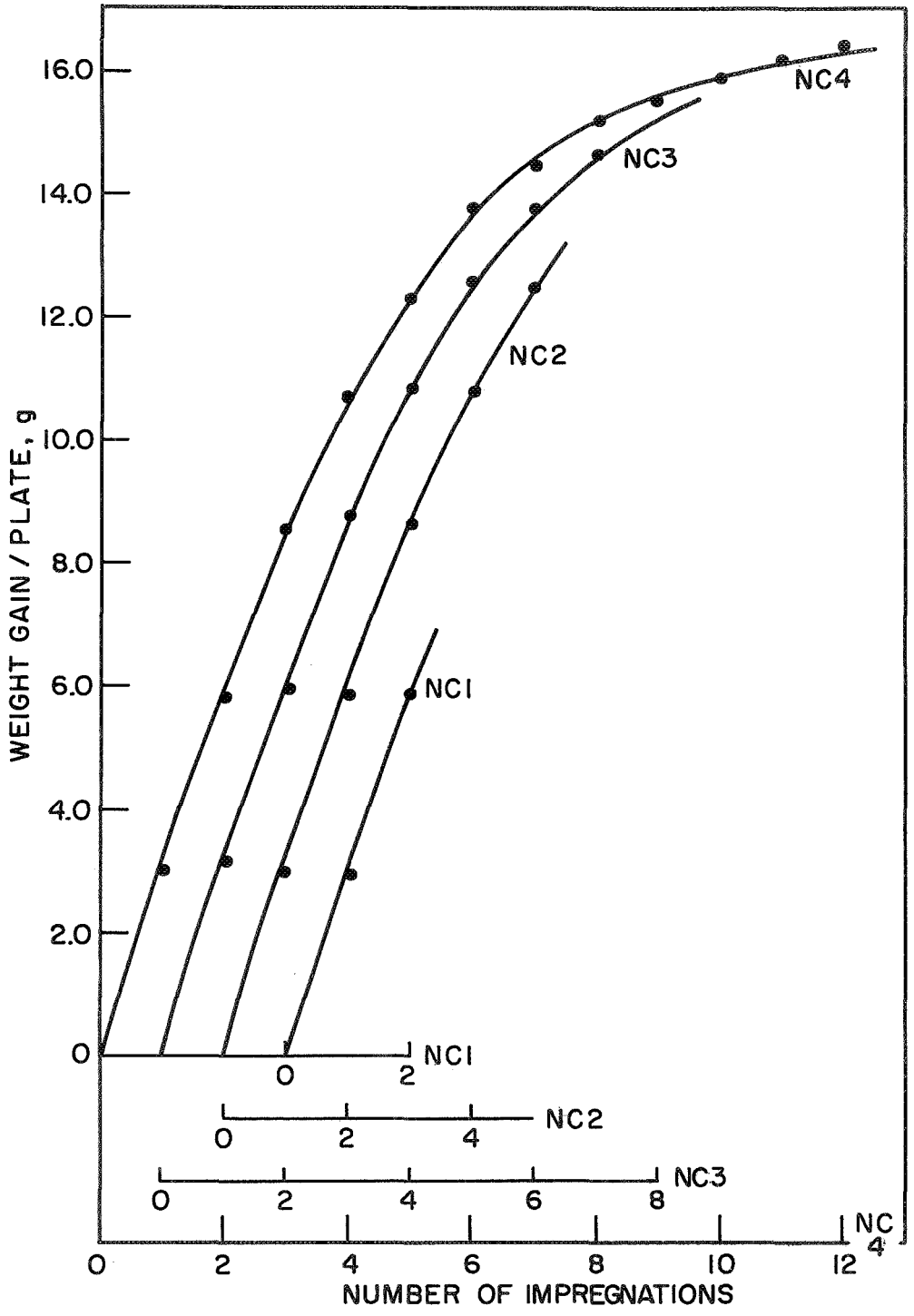

Fig. 6. Reproducibility of Fleischer process – negative plates cathodized at 150 mA/cm^2

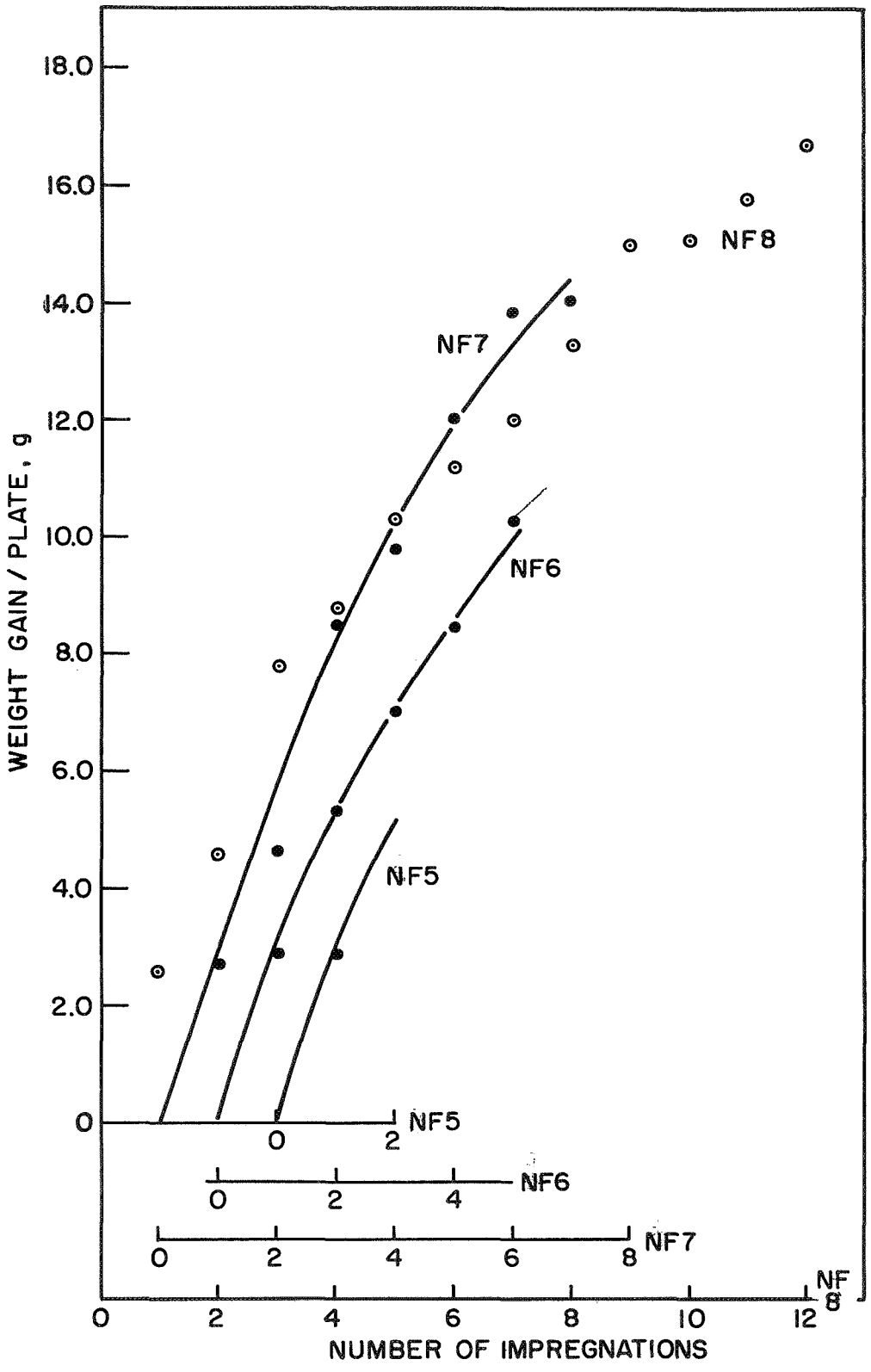

Fig. 7. Reproducibility of Fleischer process – negative plates cathodized at 300 mA/cm^2

terms of both uniformity and reproducibility at all loadings. Plate NF8 which had the largest total cadmium pickup gave a quite low capacity because of poor utilization. In general, the utilization ranged from 68 to 79% without any apparent pattern. The capacities after five impregnations or more were in excess of the commonly used capacity of ~0.4 Ahr/cm^3. The theoretical capacities listed in Table IV are based on chemical analysis of the plate to define the total cadmium content. The measured capacities were reasonably consistent except for the most heavily loaded plates.

Table V. Distribution of Cadmium g/cm^2 - Fleischer Method, Negative Plates

	Number of Impregnations	Cadmium, g/cm^2 Section A	Section C
NF1a	2	0.0467	0.0467
NF1b	2	0.048	0.047
NF2a	5	0.112	0.108
NF2b	5	0.116	0.114
NF3a	8	0.138	0.138
NF3b	8	0.203	0.132
NF4a	12	0.164	0.164
NF4b	12	0.158	0.165

D. Chemical Conversion - Negatives

The experimental measurements made on negative plates prepared by chemical conversion are recorded in Table VI. Plates NC1 through NC4 were prepared with saturated cadmium nitrate as the impregnation solution. Plates NC5 through NC8 were prepared with an impregantion solution of half-saturated concentration. Again apart from the plates that received only two impregnation cycles reasonable, reproducibility was obtained between replicate samples. Note that in this case there is no ambiguity with respect to the stoichiometry of the active material (cadmium hydroxide). Comparison of the weight gains after each impregnation cycle (Figs. 8 and 9) also indicates good reproducibility, possibly slightly better for the more concentrated solutions.

Uniformity of the distribution of active material is acceptable though the spread in values is greater than those observed with the positive plates and with the negatives prepared by the Fleischer method.

Table VI. Capacity, Weight-Gain and Utilization – Chemical Conversion, Negative Plates

	Number of Impregnations	Active Material, g/cm^2			Capacity, Ahr/cm^3		Utilization, %
		A	B	C	Theoretical	Measured*	
NC1a	2	0.0655	0.0622	0.0668	0.295	0.170	58
b		0.0583	0.0668	0.0669			
NC2a	5	0.1356	0.1417	0.1507	0.600	0.540	90
b		0.1465	0.1378	0.1423			
NC3a	8	0.1792	0.1628	0.1681	0.808	0.581	72
b		0.1786	0.1624	0.1608			
NC4a	12	0.1854	0.1821	0.1867	0.838	0.627	75
b		0.1813	0.1880	0.1912			
NC5a	2	0.0259	0.0253	0.0356	0.123	0.067	55
b		0.0280	0.0330	0.0419			
NC6a	5	0.0623	0.0584	0.0583	0.279	0.228	82
b		0.0606	0.0635	0.0708			
NC7a	8	0.0948	0.0893	0.0960	0.444	0.314	71
b		0.0977	0.0944	0.0916			
NC8a	12	0.1488	0.1371	0.1376	0.670	0.530	79
b		0.1447	0.1426	0.1388			

*Measured on piece A.

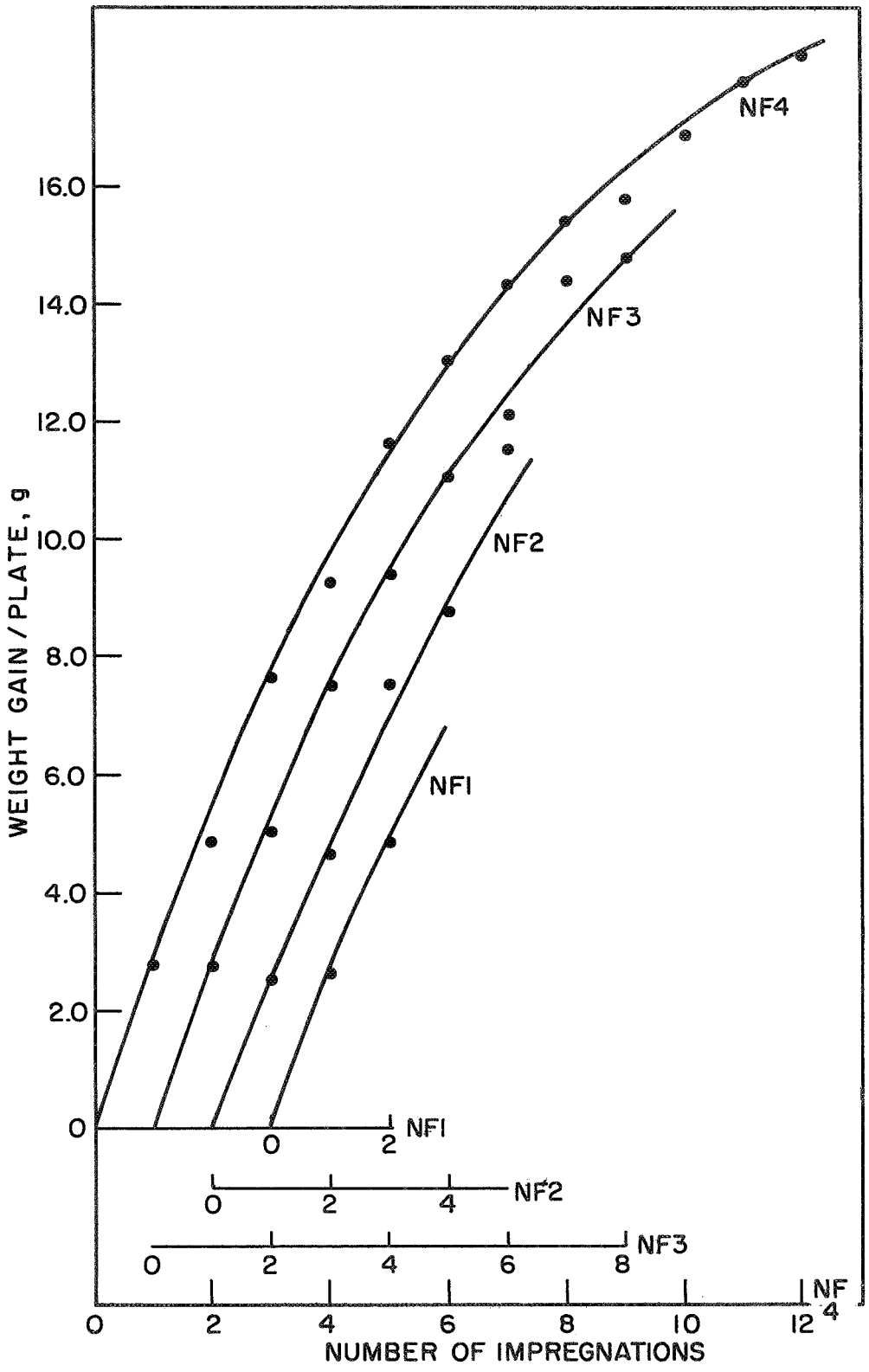

Fig. 8. Reproducibility of chemical conversion process – negative plates prepared with saturated impregnation solution

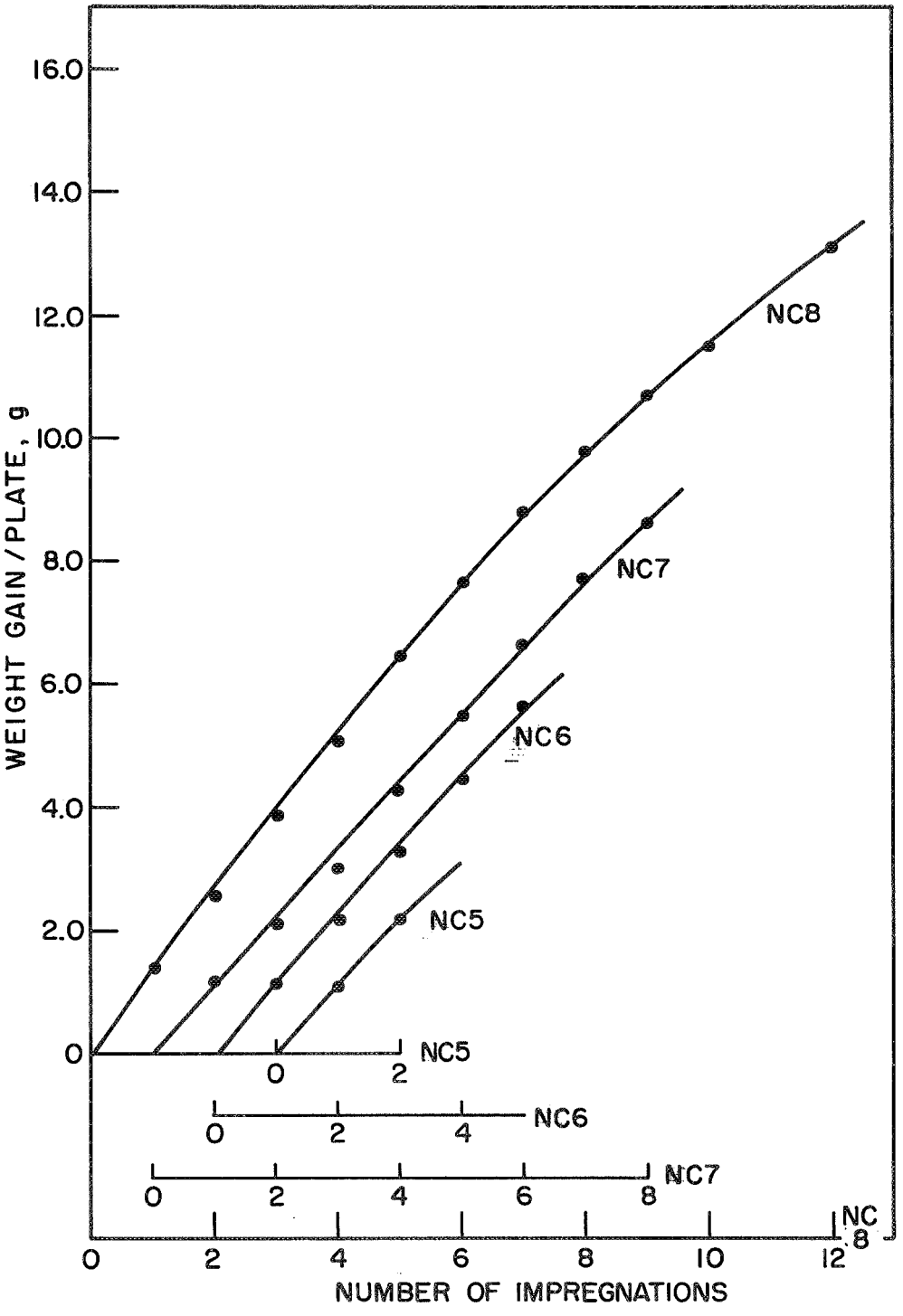

Fig. 9. Reproducibility of chemical conversion process – negative plates prepared with 50% saturated impregantion solution

The measured capacities are comparable with those of the Fleischer method. The utilization figures again show a low value for the lightly loaded plaques. It is conceivable that this low figure is a result of corrosion of the plaque which would contribute to the weight gain without contributing to capacity. The extent of corrosion is possibly independent of the number of impregnation cycles, i.e., most corrosion would occur during the first cycle, so that its effect on the higher loading plate capacities is not so noticeable. For both series of preparations NC1 to NC4 and NC5 to NC8, maximum utilization was observed for the plates with five impregnation cycles.

E. Modified Fleischer Process - Positive Plates

The modification to the process consisted of a drying step between impregnation with the nitrate and cathodization in KOH. The weight gains recorded were slightly greater than the Fleischer process, as were the measured capacities, but as is apparent from Table VII and the data sheets both reproducibility and uniformity were not as good.

Table VII. Capacity, Weight Gain and Utilization - Modified Fleischer Method, Positive Plates

	Number of Impregnations	Active Material, g/cm^2			Capacity, Ahr/cm^2		Utilization, %
		A	B	C	Theoretical	Measured	
PFF1	2	0.0389	0.0375	0.0356	0.181	0.118	65
PCF2	5	0.0807	0.0732	0.0759	0.343	0.307	90
PCF3	8	0.1158	0.1061	0.1072	0.402	0.344	86

F. Comparative Analysis of Impregnation Methods - Positives

1. Weight gain and capacity

A plot of weight gain and capacity against the number of impregnations for each preparative is presented in Fig. 10. The highest loading and highest capacity are obtained with the chemical conversion process using saturated solutions. The lowest loading and capacity also were observed for the chemical conversion process

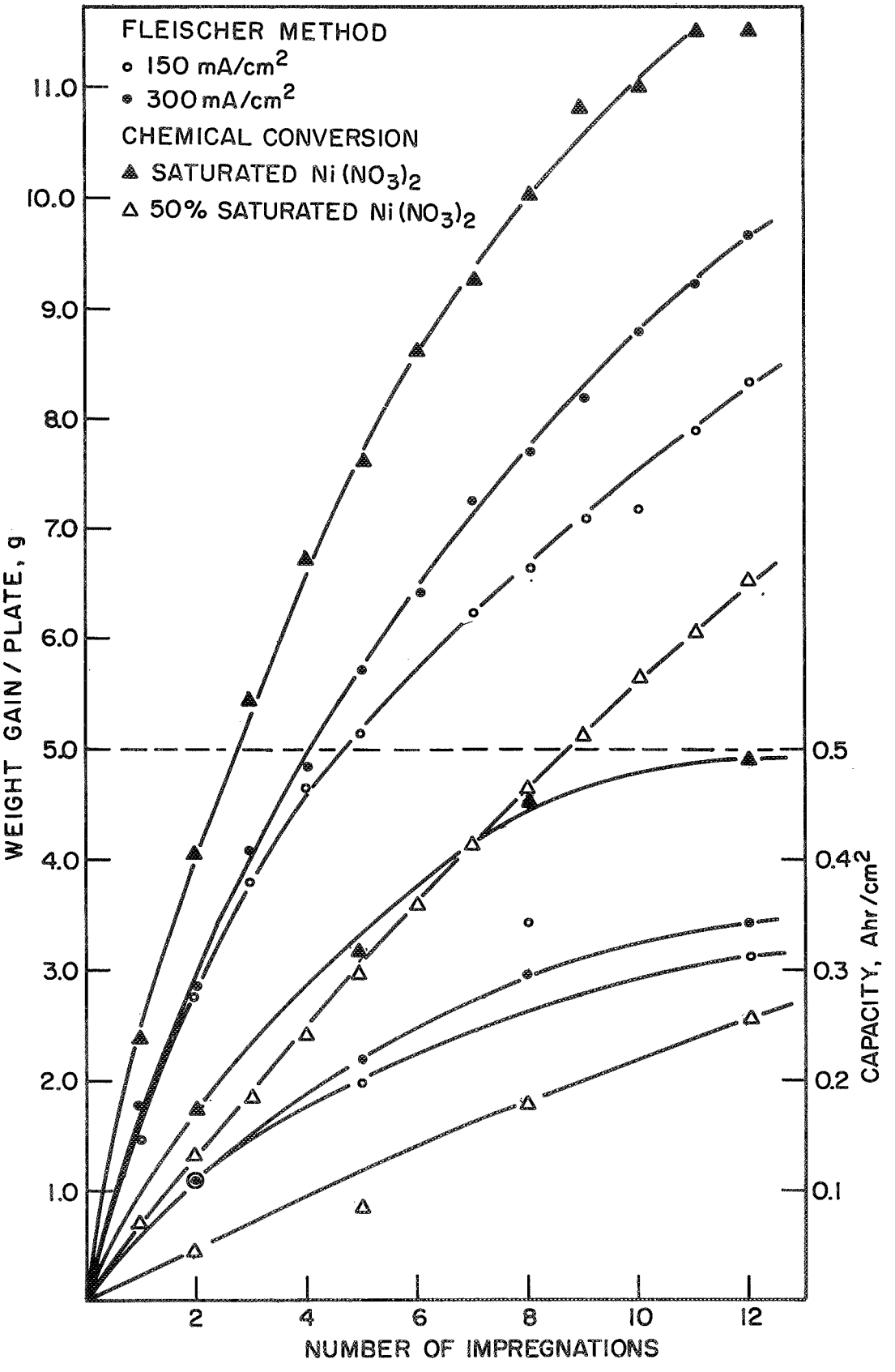

Fig. 10. Comparison of weight gain and capacity for Fleischer and chemical conversion methods – positive plates

using less concentrated solutions. From this, we may infer that control of this process is quite dependent on control of solution concentration. This remark is probably equally true of the Fleischer process though we do not have the data to confirm it.

The two sets of plates prepared by the Fleischer process do not show a marked dependance on current density, though the higher current density does produce a slightly higher loading and slightly greater capacity for the same number of impregnations.

Of greater interest, however, are the capacities at equal loading that can be derived from the plots in Fig. 10. These are presented in Table VIII. At loadings of 4.0 and 6.0 g/plate, the capacities are almost identical and moreover the Ahr/g figure of 0.04 applies to all four preparations up to a loading of 6.0 g plate. Thus, the choice of method of positive plate preparation may be made entirely on the basis of which method gives the most uniform and reproducible product. It is therefore possible to choose an optimum number of impregnations and solution concentration to give the desired loading. The optimum number of impregnation cycles can be expressed in terms of a sufficient number to produce the desired leveling effect without being so great that the probability of a nonsystematic error is unnecessarily large.

Table VIII. Capacities in Ahr/cm^3 at Equal Loading - Positive Plates

Loading , g/plate	4.0	6.0	10.0
Chemical Conversion			
Saturated $Ni(NO_3)_2$	0.17	0.26	0.45
50% Saturated $Ni(NO_3)_2$	0.16	0.24	(0.38)*
Fleischer Method			
150 mA/cm^2	0.16	0.23	(0.33)*
300 mA/cm^2	0.16	0.23	(0.35)*

*Projected figures.

2. Miscellaneous factors

It is of interest to examine some of the incidental facts that can be derived from the data collected. For example, it is apparent (Table IX) that there is more plaque corrosion during chemical conversion than in the Fleischer process (Table X). Two factors probably influence this effect. The drying step of chemical conversion in essence involves prolonged contact with nitric acid at elevated temperatures. Also the cathodization associated with the Fleischer process maintains the plaque at a potential where no corrosion of nickel can take place. During chemical conversion any oxygen present during the KOH treatment can induce corrosion of the nickel plaque where it is not fully protected by a passive film. The apparent decrease in plaque corrosion with increase in the number of impregnation cycles is probably an artifact relating to the sensitivity of the analytical procedures.

This latter comment also applies to the determination of the water content of the active material (Table IX and X), though it does appear that the water content of t the Fleischer plates prepared at 150 mA/cm^2 is greater than those prepared at 300 mA/cm^2. There is also a link between water content and utilization. Those plates with a high water content also showed the highest utilization factor.

Lastly, we may make a comparison of the surface area of the active material in various plates. Expressed in terms of m^2/g of active material, the surface area decreases as the loading increases (Fig. 11). This behavior is different from that of Jost and Rufenacht[6] who claimed no decrease in surface area as the loading was increased. However, this difference could be related to the morphology of the active material. The morphological differences associated with the two different methods of preparation are apparent in Fig. 11 in that two distinct groupings of points can be discerned.

A brief examination was made of the effect of thickness on reproducibility and uniformity. The results are presented in Table XI. The thicker plaque gave better uniformity but it is considered that this probably reflects the difference in quality of plaques rather than any fundamental effect. The measured capacities in Ahr/cm^3 were quite uniform.

G. Comparative Analysis of Impregnation Methods - Negatives

A comparison of weight gain and capacity for the different conditions of negative plate preparation is given in Fig. 12. Up to a loading of 14 g/plate, the chemical

Table IX: Plaque Corrosion – Water Content and Surface Area, Positive Plates, Fleischer Method

	Number of Impregnations	Plaque Corrosion, %	Water Content of Active Material, %	Surface Area, m^2/g active material	Utilization %
PF1a	2	4	0	152	68
PF2a	5	0	15	69	81
PF3a	8	2	12	53	91
PF4a	12	0	16	54	90
PF5a	2	3	9	129	94
PF6a	5	0	8	95	86
PF7a	8	0	8	68	91
PF8a	12	0	9	46	87

Table X. Plaque Corrosion – Water Content and Surface Area, Positive Plates, Chemical Conversion

	Number of Impregnations	Plaque Corrosion, %	Water Content of Active Material, %	Surface Area, m^2/g active material	Utilization, %
PC1a	2	8	12	118	122
PC2a	5	8	11	80	91
PC3a	8	4	13	63	99
PC4a	12	7	7	38	84
PC7a	8	3	7	–	96
PC8a	12	–	12	–	106

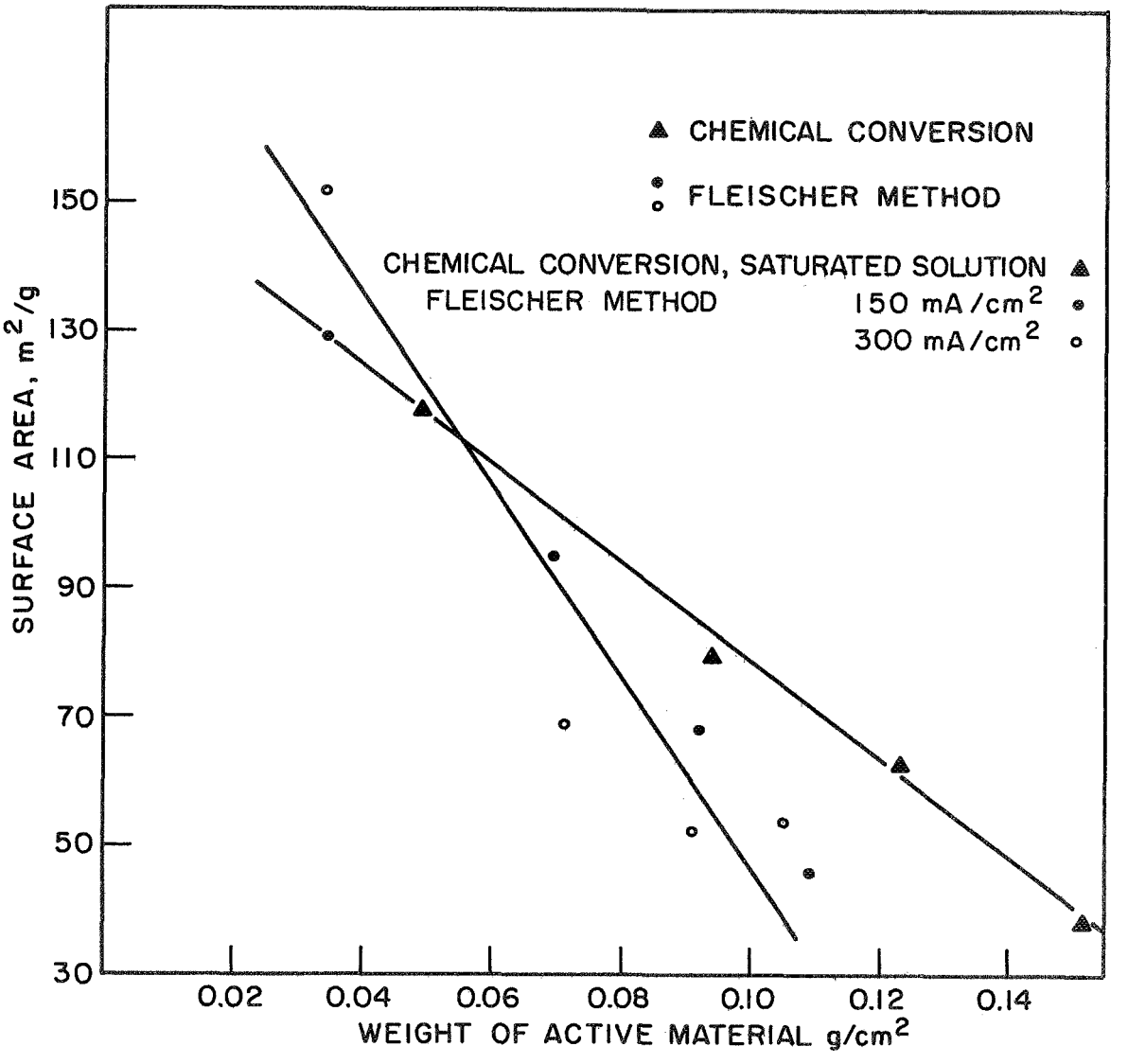

Fig. 11. Surface area as a function of weight gain

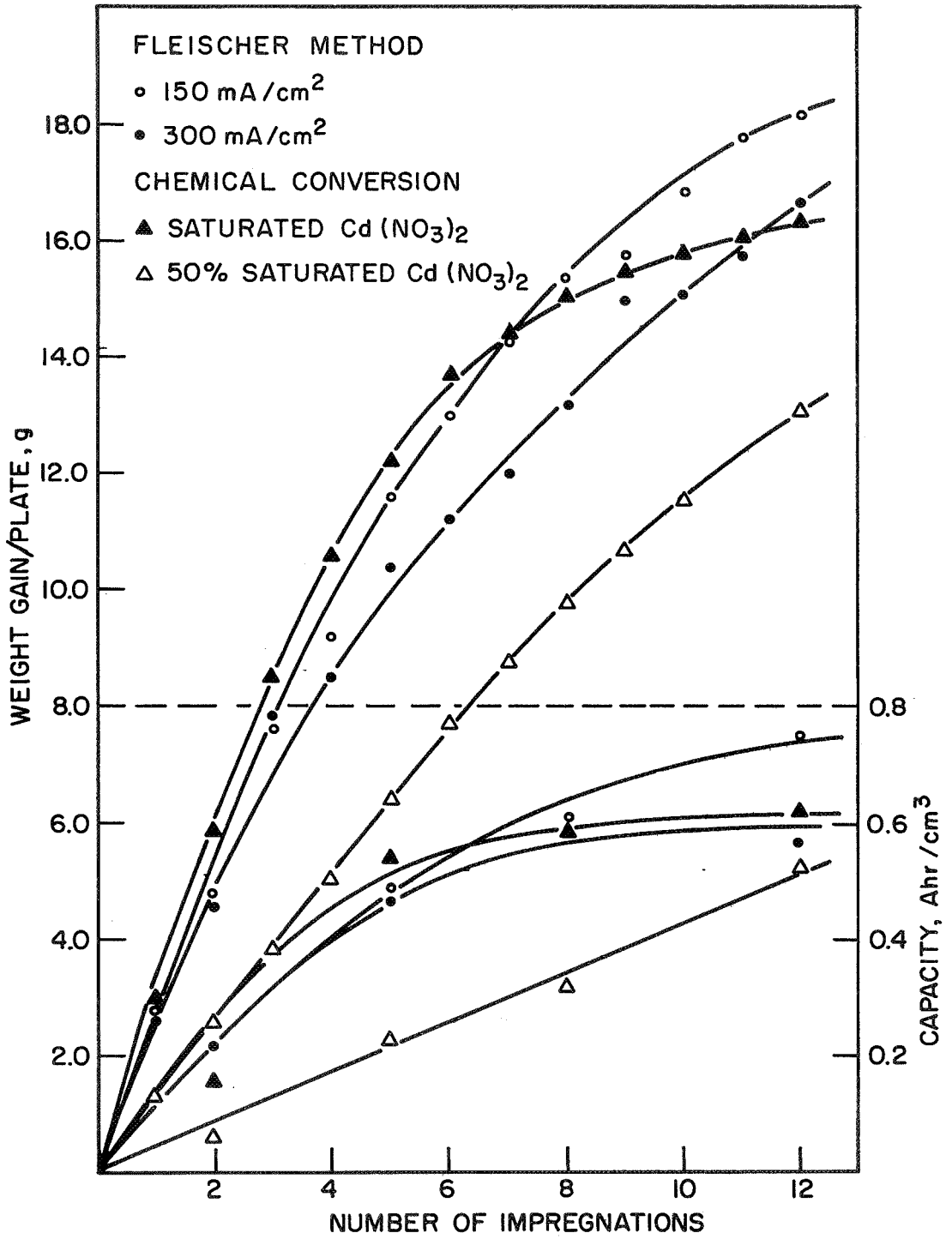

Fig. 12. Comparison of weight gain and capacity for Fleisher and chemical conversion methods – negative plates

conversion process with saturated cadmium nitrate provides the greatest weight gain. At higher loadings, however, the Fleischer method in which some of the cadmium hydroxide is reduced to the more dense cadmium metal provides a greater void volume in the plate so that it is able to pick up more active material. This pattern is reflected in the capacities also. A surprising feature is that in the Fleischer process the cathodizing at 150 mA/cm^2 is more efficient in terms of weight gain than cathodizing at 300 mA/cm^2. This could be related to the rate of gas formation in the pore structure.

Table XI. Capacity, Weight Gain, and Utilization as a Function of Thickness

Thickness, cm	Weight of Active Material, g/cm^3			Capacity, Ahr/cm^3		Utilization, %
	A	B	C	Theoretical	Measured	
0.0660	1.369	1.000	1.133	0.326	0.294	91
0.0732	1.042	0.933	1.120	0.300	0.300	100
0.0832	1.144	1.042	1.149	0.331	0.303	92
0.0879	1.088	1.065	1.083	0.305	0.318	104

However, in terms of the specific capacities at equal loadings (Table XII), the 300 mA/cm^2 figure for a 10 g loading is higher than the 150 mA/cm^2 and slightly higher than the chemical conversion. This is probably a result of differences in the morphology of the active material which is of greater importance than in the case of the positive active material. Any advantage in the Fleischer process at 300 mA/cm^2 in this respect will more than likely be offset by the much better reproducibility observed with the lower current density or in the chemical conversion process.

Table XII. Capacities in Ahr/cm^3 at Equal Loading – Negative Plates

Loading, g/plate	4.0	6.0	10.0	16.0
Chemical conversion				
Saturated $Cd(NO_3)_2$	0.17	0.26	0.44	0.62
50% Saturated $Cd(NO_3)_2$	0.13	0.20	0.35	–
Fleischer Method				
150 mA/cm^2	0.17	0.25	0.40	0.66
300 mA/cm^2	0.18	0.27	0.46	0.60

IV. CONCLUSIONS

The stated objectives of this phase of the program were to define systematic procedures for the preparation of uniform and reproducible nickel cadmium battery plates. In an ongoing program with further evaluation of these components, it is perhaps premature to be too definite at this stage. However, the work presented above cannot be allowed to stand without the salient features being summarized. Based on the above data, using the experimental techniques practiced at Tyco, it would appear that of the two processes considered the chemical conversion process provides more reproducible and uniform materials. The negative plates may be prepared most conveniently using saturated cadmium nitrate solution for impregnation. For the positive plates the less concentrated impregnation solutions provided the more uniform and reproducible plates though an inordinate number of impregnations would be required to reach normal specific capacities.

V. FUTURE WORK

Electrochemical methods of impregnation will be assessed in comparison with those described above. Further studies of the variables associated with both plaque and plate preparation will be undertaken with a view to establishing cycle life and response in operating under sealed cell conditions.

VI. REFERENCES

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2. A. Fleischer, J. Electrochem. Soc., 94, 289 (1948).
3. E.J. Casey, P.L. Bourgault and P.E. Lake, Can. J. Tech., 34, 95 (1965).
4. Fifth Quarterly Report, this contract.
5. Sixth Quarterly Report, this contract.
6. E. Jost and F. Rufenacht, J. Electrochem. Soc., 113, 97 (1966).

APPENDIX A

Impregnation of Positive Plate

IMPREGNATION DATA SHEET

Positive: PF1a

Method: Fleischer

Conditions: Saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 150 mA/cm^2

Number of cycles: 2

Plaque Data:

Size, cm^2 79.1 ; Thickness, cm 0.0749 ; Weight, g 13.0233

Density, g/cm^2 0.1646

Weight Gain, g:

1 1.4790	5	9
2 1.1886	6	10
3	7	11
4	8	12

Total Weight Gain, g 2.6676

Average weight of active material: 0.0337 g/cm^2 0.4484 g/cm^3

Distribution of active material, g/cm^2

A 0.0353

B 0.0348

C 0.0306

Theoretical capacity (section A) 0.0122 A hr/cm^2; 0.163 A hr/cm^3

Measured capacity (section A) 0.0083 A hr/cm^2; 0.111 A hr/cm^3

Utilization factor, % 68.0

Chemical Analysis - Positive Plate: PF1a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	0.1990
Weight/unit area after extraction, g/cm^2	0.1560
Active material, %	21.6
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0418
Water content of active material, %	2.5
Plaque corrosion%	5.2

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.2007
Weight/unit area after extraction, g/cm^2	0.1579
Active material, %	21.32
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0427
Water content of active material, %	0.4
Plaque corrosion %	4.0

Surface Area:

Section B, m^2/g	152

IMPREGNATION DATA SHEET

Positive: PF2a

Method: Fleischer

Conditions: Saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 150 mA/cm^2

Number of cycles: 5

Plaque Data:

Size, cm^2 79.1 ; Thickness, cm 0.0752 ; Weight, g 12.9404

Density, g/cm^2 0.1636

Weight Gain, g:

1 1.4931	5 0.8893	9
2 1.2093	6	10
3 0.9365	7	11
4 0.9282	8	12

Total Weight Gain, g 5.4564

Average weight of active material: 0.0709 g/cm^2 0.9063 g/cm^3

Distribution of active material, g/cm^2

A 0.0708

B 0.0696

C 0.0640

Theoretical capacity (section A) 0.0186 A hr/cm^2; 0.247 A hr/cm^3

Measured capacity (section A) 0.0150 A hr/cm^2; 0.1995 A hr/cm^3

Utilization factor, % 80.6

Chemical Analysis - Positive Plate: PF2a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	0.2227
Weight/unit area after extraction, g/cm^2	0.1553
Active material, %	30.3
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0638
Water content of active material, %	8.6
Plaque corrosion %	5.1

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.2371
Weight/unit area after extraction, g/cm^2	0.1641
Active material, %	30.8
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0627
Water content of active material, %	14.7
Plaque corrosion %	None

Surface Area:

Section B, m^2/g	69

IMPREGNATION DATA SHEET

Positive: PF3a

Method: Fleischer

Conditions: Saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 150 mA/cm^2

Number of cycles: 8

Plaque Data:

Size, cm^2 79.1 ; Thickness, cm 0.0770 ; Weight, g 13.5170

Density, g/cm^2 0.1709

Weight Gain, g:

1 1.5639	5		9
2 1.3222	6	1.2709	10
3 0.9901	7	0.4415	11
4 0.9115	8	0.4657	12

Total Weight Gain, g 7.2347

Average weight of active material: 0.0915 g/cm^2 1.176 g/cm^3

Distribution of active material, g/cm^2

A 0.0889

B 0.0956

C 0.0871

Theoretical capacity (section A) 0.0292 A hr/cm^2; 0.379 A hr/cm^3

Measured capacity (section A) 0.0263 A hr/cm^2; 0.347 A hr/cm^3

Utilization factor, % 91

Chemical Analysis - Positive Plate: PF3a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	0.2635
Weight/unit area after extraction, g/cm^2	0.1661
Active material, %	37.0
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0824
Water content of active material, %	15.4
Plaque corrosion %	2.9

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.2800
Weight/unit area after extraction, g/cm^2	0.1669
Active material, %	40.4
$Ni(OH)_2$ from DMG determination, g/cm^2	0.1010
Water content of active material, %	11.9
Plaque corrosion %	2.4

Surface Area:

Section B, m^2/g	53

IMPREGNATION DATA SHEET

Positive: PF4a

Method: Fleischer

Conditions: Saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 150 mA/cm^2

Number of cycles: 12

Plaque Data:

Size, cm^2 79.8 ; Thickness, cm 0.0762 ; Weight, g 13.0986

Density, g/cm^2 0.1641

Weight Gain, g:

1 1.4820	5 0.4849	9 0.4569
2 1.2820	6	10 0.0843
3 1.0432	7 1.1153	11 0.7328
4 0.8522	8 0.3883	12 0.4485

Total Weight Gain, g 7.4734

Average weight of active material: 0.0936 g/cm^2 1.1816 g/cm^3

Distribution of active material, g/cm^2

A 0.0921

B 0.0885

C 0.0913

Theoretical capacity (section A) 0.0214 A hr/cm^2; 0.281 A hr/cm^3

Measured capacity (section A) 0.0240 A hr/cm^2; 0.315 A hr/cm^3

Utilization factor, % 112

Chemical Analysis - Positive Plate: PF4a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	0.2546
Weight/unit area after extraction, g/cm^2	0.1671
Active material, %	34.4
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0736
Water content of active material, %	16.0
Corrosion of plaque %	None

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.2761
Weight/unit area after extraction, g/cm^2	0.1654
Active material, %	40.2
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0925
Water content of active material, %	16.2
Corrosion of plaque %	None

Surface Area:

Section B, m^2/g	54.3

IMPREGNATION DATA SHEET

Positive: PF5a

Method: Fleischer

Conditions: Saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 300 mA/cm^2

Number of cycles: 2

Plaque Data:

Size, cm^2 88.32 ; Thickness, cm 0.0808 ; Weight, g 14.8670

Density, g/cm^2 0.1683

Weight Gain, g:

1 1.4580	5	9
2 1.2680	6	10
3	7	11
4	8	12

Total Weight Gain, g 2.7260

Average weight of active material: 0.0339 g/cm^2 0.4195 g/cm^3

Distribution of active material, g/cm^2

A 0.0351

B 0.0358

C 0.0309

Theoretical capacity (section A) 0.0096 A hr/cm^2; 0.119 A hr/cm^3

Measured capacity (section A) 0.0090 A hr/cm^2; 0.111 A hr/cm^3

Utilization factor, % 94

Chemical Analysis - Positive Plate: PF5a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	
Weight/unit area after extraction, g/cm^2	
Active material, %	
$Ni(OH)_2$ from DMG determination, g/cm^2	
Water content of active material, %	

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.1997
Weight/unit area after extraction, g/cm^2	0.1637
Active material, %	18.0
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0328
Water content of active material, %	8.7
Corrosion of plaque %	2.8

Surface Area:

Section B, m^2/g	129

IMPREGNATION DATA SHEET

Positive: PF6a

Method: Fleischer

Conditions: Saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 300 mA/cm^2

Number of cycles: 5

Plaque Data:

Size, cm^2 88.9 ; Thickness, cm 0.0813 ; Weight, g 14.685

Density, g/cm^2 0.1651

Weight Gain, g:

1 1.369	5 0.895	9
2 1.220	6	10
3 1.112	7	11
4 1.158	8	12

Total Weight Gain, g 5.855

Average weight of active material: 0.0690 g/cm^2 0.8487 g/cm^3

Distribution of active material, g/cm^2

A 0.0671

B 0.0728

C 0.0672

Theoretical capacity (section A) 0.0210 A hr/cm^2; 0.248 A hr/cm^3

Measured capacity (section A) 0.0180 A hr/cm^2; 0.221 A hr/cm^3

Utilization factor, % 86

Chemical Analysis - Positive Plate: PF6a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	
Weight/unit area after extraction, g/cm^2	
Active material, %	
$Ni(OH)_2$ from DMG determination, g/cm^2	
Water content of active material, %	

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.2435
Weight/unit area after extraction, g/cm^2	0.1692
Active material, %	31.0
$Ni(OH)_2$ from DMG determination, g/cm^2	0.069
Water content of active material, %	8.0
Corrosion of plaque %	None

Surface Area:

Section B, m^2/g	94.8

IMPREGNATION DATA SHEET

Positive: PF7a

Method: Fleischer

Conditions: Saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 300 mA/cm^2

Number of cycles: 8

Plaque Data:

Size, cm^2 88.9 ; Thickness, cm 0.0826 ; Weight, g 14.818

Density, g/cm^2 0.1666

Weight Gain, g:

1 1.654	5 0.820	9
2 1.122	6 0.731	10
3 1.100	7 0.800	11
4 0.970	8 0.605	12

Total Weight Gain, g 7.802

Average weight of active material: 0.0920 g/cm^2 1.1151 g/cm^3

Distribution of active material, g/cm^2

A 0.0923

B 0.0928

C 0.0909

Theoretical capacity (section A) 0.0270 A hr/cm^2; 0.326 A hr/cm^3

Measured capacity (section A) 0.0246 A hr/cm^2; 0.298 A hr/cm^3

Utilization factor, % 91

Chemical Analysis - Positive Plate: PF7a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	
Weight/unit area after extraction, g/cm^2	
Active material, %	
$Ni(OH)_2$ from DMG determination, g/cm^2	
Water content of active material, %	

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.2700
Weight/unit area after extraction, g/cm^2	0.1677
Active material, %	37.9
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0924
Water content of active material, %	8.0
Corrosion of plaque %	None

Surface Area:

Section B, m^2/g	68.3

IMPREGNATION DATA SHEET

Positive: PF8a

Method: Fleischer

Conditions: Saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 300 mA/cm^2

Number of cycles: 12

Plaque Data:

Size, cm^2 88.9 ; Thickness, cm 0.808 ; Weight, g 14.790

Density, g/cm^2 0.1633

Weight Gain, g:

1	1.758	5	0.866	9	0.490
2	1.100	6	0.698	10	0.610
3	1.150	7	0.816	11	0.436
4	0.858	8	0.474	12	0.434

Total Weight Gain, g 9.690

Average weight of active material: 0.1091 g/cm^2 1.350 g/cm^3

Distribution of active material, g/cm^2: A 0.1129; B 0.1035; C 0.1111

Theoretical capacity (section A) 0.0321 A hr/cm^2; 0.398 A hr/cm^3

Measured capacity (section A) 0.0280 A hr/cm^2; 0.347 A hr/cm^3

Utilization factor, % 87

Chemical Analysis - Positive Plate: PF8a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	
Weight/unit area after extraction, g/cm^2	
Active material, %	
$Ni(OH)_2$ from DMG determination, g/cm^2	
Water content of active material, %	

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.2942
Weight/unit area after extraction, g/cm^2	0.1717
Active material, %	41.6
$Ni(OH)_2$ from DMG determination, g/cm^2	0.1102
Water content of active material, %	9.6
Corrosion of plaque %	None

Surface Area:

Section B, m^2/g	46.1

IMPREGNATION DATA SHEET

Positive: PC1a

Method: Chemical conversion

Conditions: Saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C

Number of cycles: 2

Plaque Data:

Size, cm^2 89.6 ; Thickness, cm 0.0813 ; Weight, g 14.914

Density, g/cm^2 0.1664

Weight Gain, g:

1 2.485	5	9
2 1.879	6	10
3	7	11
4	8	12

Total Weight Gain, g 4.364

Average weight of active material: 0.0487 g/cm^2 0.6223 g/cm^3

Distribution of active material, g/cm^2

A 0.0529

B 0.0485

C 0.0504

Theoretical capacity (section A) 0.0115 A hr/cm^2; 0.141 A hr/cm^3

Measured capacity (section A) 0.0141 A hr/cm^2; 0.173 A hr/cm^3

Utilization factor, % 122

Chemical Analysis - Positive Plate: PC1a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	
Weight/unit area after extraction, g/cm^2	
Active material, %	
$Ni(OH)_2$ from DMG determination, g/cm^2	
Water content of active material, %	

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.2162
Weight/unit area after extraction, g/cm^2	0.1526
Active material, %	29.4
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0394
Water content of active material, %	11.9
Corrosion of plaque %	8.3

Surface Area:

Section B, m^2/g	118

IMPREGNATION DATA SHEET

Positive: PC2a

Method: Chemical conversion

Conditions: Saturated $Ni(NO_3)_2$ + nitric acid 25% KOH at 80 °C

Number of cycles: 5

Plaque Data:

Size, cm^2 89.6 ; Thickness, cm 0.0813 ; Weight, g 14.973

Density, g/cm^2 0.1671

Weight Gain, g:

1 2.477	5 1.248	9
2 1.735	6	10
3 1.530	7	11
4 1.442	8	12

Total Weight Gain, g 8.432

Average weight of active material: 0.0941 g/cm^2 1.2041 g/cm^3

Distribution of active material, g/cm^2

A 0.0984

B 0.0944

C 0.1011

Theoretical capacity (section A) 0.0274 A hr/cm^2; 0.328 A hr/cm^3

Measured capacity (section A) 0.0255 A hr/cm^2; 0.314 A hr/cm^3

Utilization factor, % 91

Chemical Analysis - Positive Plate: PC2a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	
Weight/unit area after extraction, g/cm^2	
Active material, %	
$Ni(OH)_2$ from DMG determination, g/cm^2	
Water content of active material, %	

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.2602
Weight/unit area after extraction, g/cm^2	0.1542
Active material, %	40.8
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0942
Water content of active material, %	11.0
Corrosion of plaque %	7.7

Surface Area:

Section B, m^2/g	80

IMPREGNATION DATA SHEET

Positive: PC3a

Method: Chemical conversion

Conditions: Saturated $Ni(NO_3)_2$ + nitric acid 25% KOH at 80 °C

Number of cycles: 8

Plaque Data:

Size, cm^2 77.0 ; Thickness, cm 0.0812 ; Weight, g 13.005

Density, g/cm^2 0.1689

Weight Gain, g:

1 2.210	5 0.888	9
2 1.591	6 0.970	10
3 1.349	7 0.663	11
4 1.132	8 0.640	12

Total Weight Gain, g 9.445

Average weight of active material: 0.1229 g/cm^2 1.5455g/cm^3

Distribution of active material, g/cm^2

A 0.1282

B 0.1235

C 0.1250

Theoretical capacity (section A) 0.3715 A hr/cm^2; 0.457 A hr/cm^3

Measured capacity (section A) 0.0367 A hr/cm^2; 0.452 A hr/cm^3

Utilization factor, % 99

Chemical Analysis - Positive Plate: PC3a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	
Weight/unit area after extraction, g/cm^2	
Active material, %	
$Ni(OH)_2$ from DMG determination, g/cm^2	
Water content of active material, %	

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.3101
Weight/unit area after extraction, g/cm^2	0.1628
Active material, %	47.5
$Ni(OH)_2$ from DMG determination, g/cm^2	0.1273
Water content of active material, %	13.4
Corrosion of plaque %	3.6

Surface Area:

Section B, m^2/g	63

IMPREGNATION DATA SHEET

Positive: PC4a

Method: Chemical conversion

Conditions: Saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C

Number of cycles: 12

Plaque Data:

Size, cm^2 81.8 ; Thickness, cm 0.0813 ; Weight, g 13.786

Density, g/cm^2 0.1686

Weight Gain, g:

1	2.386	5	0.920	9	0.811
2	1.668	6	0.982	10	0.225
3	1.376	7	0.660	11	0.572
4	1.287	8	0.740	12	0.040

Total Weight Gain, g 11.667

Average weight of active material: 0.1522 g/cm^2 1.872 g/cm^3

Distribution of active material, g/cm^2

A 0.1523

B 0.1564

C 0.1479

Theoretical capacity (section A) 0.0474 A hr/cm^2; 0.5831 A hr/cm^3

Measured capacity (section A) 0.0399 A hr/cm^2; 0.4911 A hr/cm^3

Utilization factor, % 84

Chemical Analysis - Positive Plate: PC4a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	
Weight/unit area after extraction, g/cm^2	
Active material, %	
$Ni(OH)_2$ from DMG determination, g/cm^2	
Water content of active material, %	

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.3303
Weight/unit area after extraction, g/cm^2	0.1560
Active material, %	52.8
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0163
Water content of active material, %	

Surface Area:

Section B, m^2/g	38.0

IMPREGNATION DATA SHEET

Positive: PC5a

Method: Chemical conversion

Conditions: 50% saturated $Ni(NO_3)_2$ +nitric acid, 10% KOH at 80 °C

Number of cycles: 2

Plaque Data:

Size, cm^2 88.2 ; Thickness, cm 0.0813 ; Weight, g 14.673

Density, g/cm^2 0.1663

Weight Gain, g:

1 0.734	5	9
2 0.646	6	10
3	7	11
4	8	12

Total Weight Gain, g 1.480

Average weight of active material: 0.0153 g/cm^2 0.1881 g/cm^3

Distribution of active material, g/cm^2

A 0.0150

B 0.0155

C 0.0155

Theoretical capacity (section A) A hr/cm^2; A hr/cm^3

Measured capacity (section A) A hr/cm^2; A hr/cm^3

Utilization factor, %

Not tes ted

IMPREGNATION DATA SHEET

Positive: PC6a

Method: Chemical conversion

Conditions: 50% saturated $Ni(NO_3)_2$ +nitric acid, 10% KOH at 80 °C

Number of cycles: 5

Plaque Data:

Size, cm^2 88.9 ; Thickness, cm 0.813 ; Weight, g 14.720

Density, g/cm^2 0.1665

Weight Gain, g:

1 0.754	5 0.583	9
2 0.580	6	10
3 0.578	7	11
4 0.573	8	12

Total Weight Gain, g 3.068

Average weight of active material: 0.0336 g/cm^2 0.4133 g/cm^3

Distribution of active material, g/cm^2

A 0.0311

B 0.0351

C 0.0347

Theoretical capacity (section A) 0.0078 A hr/cm^2; 0.096 A hr/cm^3

Measured capacity (section A) 0.0071 A hr/cm^2; 0.087 A hr/cm^3

Utilization factor, % 91

IMPREGNATION DATA SHEET

Positive: PC7a

Method: Chemical conversion

Conditions: 50% saturated $Ni(NO_3)_2$ + nitric acid, 10% KOH at 80 °C

Number of cycles: 8

Plaque Data:

Size, cm^2 88.6 ; Thickness, cm 0.0813 ; Weight, g 14.788

Density, g/cm^2 0.1669

Weight Gain, g:

1 0.717	5 0.615	9
2 0.608	6 0.600	10
3 0.577	7 0.520	11
4 0.559	8 0.502	12

Total Weight Gain, g 4.698

Average weight of active material: 0.0493 g/cm^2 0.6063 g/cm^3

Distribution of active material, g/cm^2

A 0.0506

B 0.0480

C 0.0494

Theoretical capacity (section A) 0.0153 A hr/cm^2; 0.188 A hr/cm^3

Measured capacity (section A) 0.0147 A hr/cm^2; 0.181 A hr/cm^3

Utilization factor, % 96

Chemical Analysis - Positive Plate: PC7a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	
Weight/unit area after extraction, g/cm^2	
Active material, %	
$Ni(OH)_2$ from DMG determination, g/cm^2	
Water content of active material, %	

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.2200
Weight/unit area after extraction, g/cm^2	0.1635
Active material, %	25.7
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0529
Water content of active material, %	6.6
Plaque corrosion %	2.8

Surface Area:

Section B, m^2/g	

IMPREGNATION DATA SHEET

Positive: PC8a

Method: Chemical conversion

Conditions: 50% $Ni(NO_3)_2$ + nitric acid, 10% KOH at 80 °C

Number of cycles: 12

Plaque Data:

Size, cm^2 88.9 ; Thickness, cm 0.0820 ; Weight, g 14.793

Density, g/cm^2 0.1664

Weight Gain, g:

1	0.727	5	0.530	9	0.535
2	0.598	6	0.605	10	0.460
3	0.540	7	0.525	11	0.440
4	0.607	8	0.500	12	0.495

Total Weight Gain, g 6.562

Average weight of active material: 0.0737 g/cm^2 0.8987 g/cm^3

Distribution of active material, g/cm^2

A 0.0747

B 0.0730

C 0.0734

Theoretical capacity (section A) 0.0202 A hr/cm^2; 0.246 A hr/cm^3

Measured capacity (section A) 0.0214 A hr/cm^2; 0.261 A hr/cm^3

Utilization factor, % 106

Chemical Analysis - Positive Plate: PC8a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	
Weight/unit area after extraction, g/cm^2	
Active material, %	
$Ni(OH)_2$ from DMG determination, g/cm^2	
Water content of active material, %	

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.2464
Weight/unit area after extraction, g/cm^2	0.1670
Active material, %	32.2
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0699
Water content of active material, %	11.9
Plaque corrosion %	None

Surface Area:

Section B, m^2/g	

IMPREGNATION DATA SHEET

Positive: PCF1a

Method: Fleischer with intermediate drying

Conditions: Saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 150 mA/cm^2

Number of cycles: 2

Plaque Data:

Size, cm^2 86.9 ; Thickness, cm 0.0777 ; Weight, g 14.170

Density, g/cm^2 0.1629

Weight Gain, g:

1 1.930	5	9
2 1.270	6	10
3	7	11
4	8	12

Total Weight Gain, g 3.200

Average weight of active material: 0.0373 g/cm^2 (0.4800 g/cm^3)

Distribution of active material, g/cm^2

A 0.0389

B 0.0375

C 0.0356

Theoretical capacity (section A) 0.0141 A hr/cm^2; 0.182 A hr/cm^3

Measured capacity (section A) 0.0092 A hr/cm^2; 0.118 A hr/cm^3

Utilization factor, % 65

Chemical Analysis - Positive Plate: PCF1a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	
Weight/unit area after extraction, g/cm^2	
Active material, %	
$Ni(OH)_2$ from DMG determination, g/cm^2	
Water content of active material, %	

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.2160
Weight/unit area after extraction, g/cm^2	0.1596
Active material, %	26.1
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0485
Water content of active material, %	13.4
Corrosion of plaque	8.2

Surface Area:

Section B, m^2/g	126

IMPREGNATION DATA SHEET

Positive: PCF2a

Method: Fleischer with intermediate drying

Conditions: Saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 150 mA/cm^2

Number of cycles: 5

Plaque Data:

Size, cm^2 87.6 ; Thickness, cm 0.0762 ; Weight, g 14.201

Density, g/cm^2 0.1620

Weight Gain, g:

1 1.620	5 1.040	9
2 1.300	6	10
3 2.462	7	11
4	8	12

Total Weight Gain, g 6.422

Average weight of active material: 0.0766 g/cm^2 1.005 g/cm^3

Distribution of active material, g/cm^2

A 0.0807

B 0.0732

C 0.0759

Theoretical capacity (section A) 0.0265 A hr/cm^2; 0.348 A hr/cm^3

Measured capacity (section A) 0.0234 A hr/cm^2; 0.307 A hr/cm^3

Utilization factor, % 88

Chemical Analysis - Positive Plate: PCF2a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	
Weight/unit area after extraction, g/cm^2	
Active material, %	
$Ni(OH)_2$ from DMG determination, g/cm^2	
Water content of active material, %	

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.2631
Weight/unit area after extraction, g/cm^2	0.1618
Active material, %	38.5
$Ni(OH)_2$ from DMG determination, g/cm^2	0.0906
Water content of active material, %	10.2
Corrosion of plaque %	None

Surface Area:

Section B, m^2/g	76.5

IMPREGNATION DATA SHEET

Positive: PCF3a

Method: Fleischer with intermediate drying

Conditions: Saturated $Ni(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 150 mA/cm^2

Number of cycles: 8

Plaque Data:

Size, cm^2 86.9 ; Thickness, cm 0.0813 ; Weight, g 14.670

Density, g/cm^2 0.1687

Weight Gain, g:

1	1.694	5 1.090	9
2	1.340	6 1.020	10
3, 4	2.685	7 0.882	11
		8 0.860	12

Total Weight Gain, g 9.820

Average weight of active material: 0.1097 g/cm^2 1.349 g/cm^3

Distribution of active material, g/cm^2: A 0.1158; B 0.1061; C 0.1072

Theoretical capacity (section A) 0.0328 A hr/cm^2; 0.404 A hr/cm^3

Measured capacity (section A) 0.0280 A hr/cm^2; 0.344 A hr/cm^3

Utilization factor, % 86

Chemical Analysis - Positive Plate: PCF3a

Green Plate - Section A:

Weight/unit area before extraction, g/cm^2	
Weight/unit area after extraction, g/cm^2	
Active material, %	
$Ni(OH)_2$ from DMG determination, g/cm^2	
Water content of active material, %	

Discharged State - Section A:

Weight/unit area before extraction, g/cm^2	0.2884
Weight/unit area after extraction, g/cm^2	0.1587
Active material, %	45.0
$Ni(OH)_2$ from DMG determination, g/cm^2	0.1130
Water content of active material, %	11.9
Corrosion of plaque %	6.0

Surface Area:

Section B, m^2/g	57.6

APPENDIX B

Impregnation of Negative Plates

IMPREGNATION DATA SHEET

Negative: NF1a

Method: Fleischer

Conditions: Saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 150 mA/cm^2

Number of cycles: 2

Plaque Data:

Size, cm^2 91.0 ; Thickness, cm 0.0824 ; Weight, g 15.1069

Density, g/cm^2 0.1660

Weight Gain, g:

1 2.6003	5	9
2 2.2632	6	10
3	7	11
4	8	12

Total Weight Gain, g 4.8635

Average weight of active material: 0.0535 g/cm^2 0.656 g/cm^3

Distribution of active material, g/cm^2

A 0.0469

B 0.0649

C 0.0524

Theoretical capacity (section C) 0.0222 A hr/cm^2; 0.304 A hr/cm^3

Measured capacity (section C) 0.0169 A hr/cm^2; 0.207 A hr/cm^3

Utilization factor, % 76.2

Chemical Analysis - Negative Plate: NF1a

	Section A	Section C
Weight of sample, g/cm^2	0.2241	0.2329
Weight of cadmium in discharged state, g/cm^2	0.0499	0.0294
Cd in discharged state, %	83.7	63.2
Weight of cadmium in charged state, g/cm^2	0.0068	0.0171
Cd in charged state, %	16.3	36.8
Total weight of Cd, g/cm^2	0.0467	0.0465
Plaque corrosion	49%	

IMPREGNATION DATA SHEET

Negative: NF2a

Method: Fleischer

Conditions: Saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 150 mA/cm^2

Number of cycles: 5

Plaque Data:

Size, cm^2 91 ; Thickness, cm 0.0818 ; Weight, g 15.0520

Density, g/cm^2 0.1654

Weight Gain, g:

1 2.5232	5 2.7702	9
2 2.1436	6	10
3 2.8639	7	11
4 1.2065	8	12

Total Weight Gain, g 11.5074

Average weight of active material: 0.1265 g/cm^2 0.155 g/cm^3

Distribution of active material, g/cm^2

A 0.1337

B 0.1259

C 0.1208

Theoretical capacity (section A) 0.0539 A hr/cm^2; 0.658 A hr/cm^3

Measured capacity (section A) 0.0402 A hr/cm^2; 0.492 A hr/cm^3

Utilization factor, % 75

Chemical Analysis - Negative Plate: NF2a

	Section A	Section C
Weight of sample, g/cm^2	0.3134	0.2975
Weight of cadmium in discharged state, g/cm^2	0.0796	0.0603
Cd in discharged state, %	70.6	55.6
Weight of cadmium in charged state, g/cm^2	0.0331	0.0482
Cd in charged state, %	20.4	44.4
Total weight of Cd, g/cm^2	0.1128	0.1086

IMPREGNATION DATA SHEET

Negative: NF3a

Method: Fleischer

Conditions: Saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 150 mA/cm^2

Number of cycles: 8

Plaque Data:

Size, cm^2 91.0 ; Thickness, cm 0.0813 ; Weight, g 15.1192

Density, g/cm^2 0.1662

Weight Gain, g:

1	2.7470	5	1.5788	9	
2	2.2771	6	1.1056	10	
3	2.4878	7	2.3154	11	
4	1.9327	8	0.3987	12	

Total Weight Gain, g 14.8431

Average weight of active material: 0.1631 g/cm^2 2.005 g/cm^3

Distribution of active material, g/cm^2: A 0.1662; B 0.1699; C 0.1632

Theoretical capacity (section A) 0.0657 A hr/cm^2; 0.808 A hr/cm^3

Measured capacity (section A) 0.0479 A hr/cm^2; 0.590 A hr/cm^3

Utilization factor, % 74

Chemical Analysis - Negative Plate: NF3a

	Section A	Section C
Weight of sample, g/cm^2	0.3463	0.3429
Weight of cadmium in discharged state, g/cm^2	0.1149	0.0938
Cd in discharged state, %	84	68
Weight of cadmium in charged state, g/cm^2	0.0216	0.0447
Cd in charged state, %	16	32
Total weight of Cd, g/cm^2	0.1378	0.1385

IMPREGNATION DATA SHEET

Negative: NF4a

Method: Fleischer

Conditions: Saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 150 mA/cm^2

Number of cycles: 12

Plaque Data:

Size, cm^2 91 ; Thickness, cm 0.0817 ; Weight, g 15.0060

Density, g/cm^2 0.1649

Weight Gain, g:

1	2.8162	5	2.3935	9	0.4211
2	2.0532	6	1.3992	10	1.1017
3	2.7565	7	1.2546	11	0.8888
4	1.6059	8	1.1409	12	0.4149

Total Weight Gain, g 18.0465

Average weight of active material: 0.1983 g/cm^2 0.243 g/cm^3

Distribution of active material, g/cm^2

A	0.2018
B	0.2121
C	0.1928

Theoretical capacity (section A) 0.0782 A hr/cm^2; 0.9561 A hr/cm^3

Measured capacity (section A) 0.0593 A hr/cm^2; 0.726 A hr/cm^3

Utilization factor, % 76

Chemical Analysis - Negative Plate: NF4a

	Section A	Section C
Weight of sample, g/cm^2	0.3616	0.3576
Weight of cadmium in discharged state, g/cm^2	0.1211	0.0830
Cd in discharged state, %	74	51
Weight of cadmium in charged state, g/cm^2	0.0429	0.0811
Cd in charged state, %	26	49
Total weight of Cd, g/cm^2	0.1640	0.1640

IMPREGNATION DATA SHEET

Negative: NF5a

Method: Fleischer

Conditions: Saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 300 mA/cm^2

Number of cycles: 2

Plaque Data:

Size, cm^2 91 ; Thickness, cm 0.0817 ; Weight, g 15.1795

Density, g/cm^2 0.1668

Weight Gain, g:

1 2.8992	5	9
2 2.2970	6	10
3	7	11
4	8	12

Total Weight Gain, g 5.1962

Average weight of active material: 0.0571 g/cm^2 0.700 g/cm^3

Distribution of active material, g/cm^2

A 0.0430

B 0.0664

C 0.0682

Theoretical capacity (section A) 0.0227 A hr/cm^2; 0.279 A hr/cm^3

Measured capacity (section A) 0.0174 A hr/cm^2; 0.213 A hr/cm^3

Utilization factor, % 76

Chemical Analysis - Negative Plate: NF5a

	Section A	Section C
Weight of sample, g/cm^2	0.2252	0.2392
Weight of cadmium in discharged state, g/cm^2	0.0190	0.0257
Cd in discharged state, %	40	43
Weight of cadmium in charged state, g/cm^2	0.0289	0.0333
Cd in charged state, %	60	57
Total weight of Cd, g/cm^2	0.0477	0.0588

IMPREGNATION DATA SHEET

Negative: NF6a

Method: Fleischer

Conditions: Saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 300 mA/cm^2

Number of cycles: 5

Plaque Data:

Size, cm^2 91 ; Thickness, cm 0.0784 ; Weight, g 15.0251

Density, g/cm^2 0.1651

Weight Gain, g:

1 2.900	5 1.8053	9
2 2.3778	6	10
3 1.7012	7	11
4 1.4754	8	12

Total Weight Gain, g 10.2597

Average weight of active material: 0.1138 g/cm^2 1.44 g/cm^3

Distribution of active material, g/cm^2: A 0.1162; B 0.1198; C 0.1360

Theoretical capacity (section A) 0.0488 A hr/cm^2; 0.601 A hr/cm^3

Measured capacity (section A) 0.0385 A hr/cm^2; 0.474 A hr/cm^3

Utilization factor, % 79

Chemical Analysis - Negative Plate: NF6a

	Section A	Section C
Weight of sample, g/cm^2	0.2817	0.2783
Weight of cadmium in discharged state, g/cm^2	0.0441	0.0289
Cd in discharged state, %	43	27
Weight of cadmium in charged state, g/cm^2	0.0584	0.0773
Cd in charged state, %	57	73
Total weight of Cd, g/cm^2	0.1026	0.1062

IMPREGNATION DATA SHEET

Negative: NF7a

Method: Fleischer

Conditions: Saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 300 mA/cm^2

Number of cycles: 8

Plaque Data:

Size, cm^2 91 ; Thickness, cm 0.0814 ; Weight, g 15.1889

Density, g/cm^2 0.1669

Weight Gain, g:

1	2.6754	5	0.09764	9	
2	1.9041	6	2.1455	10	
3	1.8230	7	1.8709	11	
4	2.4539	8	0.3098	12	

Total Weight Gain, g 14.1581

Average weight of active material: 0.1555 g/cm^2 1.912 g/cm^3

Distribution of active material, g/cm^2: A 0.1563; B 0.1635; C 0.1567

Theoretical capacity (section A) 0.0670 A hr/cm^2; 0.823 A hr/cm^3

Measured capacity (section A) 0.0483 A hr/cm^2; 0.593 A hr/cm^3

Utilization factor, % 71

Chemical Analysis - Negative Plate: NF7a

	Section A	Section C
Weight of sample, g/cm^2	0.3330	0.3175
Weight of cadmium in discharged state, g/cm^2	0.0779	0.0340
Cd in discharged state, %	55	24
Weight of cadmium in charged state, g/cm^2	0.0628	0.1055
Cd in charged state, %	45	76
Total weight of Cd, g/cm^2	0.1407	0.1395

IMPREGNATION DATA SHEET

Negative: NF8a

Method: Fleischer

Conditions: Saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C, 300 mA/cm^2

Number of cycles: 12

Plaque Data:

Size, cm^2 90.6 ; Thickness, cm 0.0820 ; Weight, g 15.437

Density, g/cm^2 0.1671

Weight Gain, g:

1	2.6442	5	1.9362	9	1.8021
2	1.9923	6	0.7950	10	0.0533
3	3.1966	7	0.8087	11	0.7622
4	0.6362	8	1.2583	12	0.8788

Total Weight Gain, g 16.7639

Average weight of active material: 0.1848 g/cm^2 2.255 g/cm^3

Distribution of active material, g/cm^2

A 0.1807

B 0.1915

C 0.2006

Theoretical capacity (section A) 0.0966 A hr/cm^2; 1.179 A hr/cm^3

Measured capacity (section A) 0.0472 A hr/cm^2; 0.576 A hr/cm^3

Utilization factor, % 49

Chemical Analysis - Negative Plate: NF8a

	Section A	Section C
Weight of sample, g/cm^2	0.3577	0.3705
Weight of cadmium in discharged state, g/cm^2	0.0175	0.0170
Cd in discharged state, %	9	9
Weight of cadmium in charged state, g/cm^2	0.1852	0.1797
Cd in charged state, %	91	91
Total weight of Cd, g/cm^2	0.2028	0.1967

IMPREGNATION DATA SHEET

Negative: NC1a

Method: Chemical conversion

Conditions: Saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C

Number of cycles: 2

Plaque Data:

Size, cm^2 88.2 ; Thickness, cm 0.0812 ; Weight, g 14.8288

Density, g/cm^2 0.1681

Weight Gain, g:

1 2.9956	5	9
2 2.8629	6	10
3	7	11
4	8	12

Total Weight Gain, g 5.8585

Average weight of active material: 0.0664 g/cm^2 0.818 g/cm^3

Distribution of active material, g/cm^2

A 0.0655

B 0.0622

C 0.0668

Theoretical capacity (section A) 0.0239 A hr/cm^2; 0.295 A hr/cm^3

Measured capacity (section A) 0.0138 A hr/cm^2; 0.170 A hr/cm^3

Utilization factor, % 58

IMPREGNATION DATA SHEET

Negative: NC2a

Method: Chemical conversion

Conditions: Saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C

Number of cycles: 5

Plaque Data:

Size, cm^2 88.2 ; Thickness, cm 0.0826 ; Weight, g 14.5752

Density, g/cm^2 0.1652

Weight Gain, g:

1 2.9844	5 1.6963	9
2 2.8668	6	10
3 2.8171	7	11
4 2.1183	8	12

Total Weight Gain, g 12.4829

Average weight of active material: 0.1415 g/cm^2 1.715 g/cm^3

Distribution of active material, g/cm^2

A 0.1356

B 0.1417

C 0.1507

Theoretical capacity (section A) 0.0496 A hr/cm^2; 0.600 A hr/cm^3

Measured capacity (section A) 0.0447 A hr/cm^2; 0.540 A hr/cm^3

Utilization factor, % 90

IMPREGNATION DATA SHEET

Negative: NC4a

Method: Chemical conversion

Conditions: Saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C

Number of cycles: 12

Plaque Data:

Size, cm^2 87.5 ; Thickness, cm 0.0810 ; Weight, g 14.6473

Density, g/cm^2 0.1673

Weight Gain, g:

1 3.0313	5 1.6339	9 0.3866
2 2.8229	6 1.4538	10 0.3596
3 2.6511	7 0.7381	11 0.2763
4 2.1226	8 0.6785	12 0.2401

Total Weight Gain, g 16.3948

Average weight of active material: 0.1875 g/cm^2 2.315 g/cm^3

Distribution of active material, g/cm^2: A 0.1854; B 0.1821; C 0.1867

Theoretical capacity (section A) 0.0679 A hr/cm^2; 0.838 A hr/cm^3

Measured capacity (section A) 0.0508 A hr/cm^2; 0.627 A hr/cm^3

Utilization factor, % 75

IMPREGNATION DATA SHEET

Negative: NC3a

Method: Chemical conversion

Conditions: Saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C

Number of cycles: 8

Plaque Data:

Size, cm^2 87.5 ; Thickness, cm 0.0826 ; Weight, g 14.7889

Density, g/cm^2 0.1690

Weight Gain, g:

1 3.0133	5 1.7135	9
2 2.8739	6 1.2367	10
3 2.7229	7 1.0131	11
4 2.1284	8 0.5411	12

Total Weight Gain, g 15.2429

Average weight of active material: 0.1742 g/cm^2 2.115 g/cm^3

Distribution of active material, g/cm^2: A 0.1792; B 0.1628; C 0.1681

Theoretical capacity (section A) 0.0656 A hr/cm^2; 0.808 A hr/cm^3

Measured capacity (section A) 0.0472 A hr/cm^2; 0.581 A hr/cm^3

Utilization factor, % 72

IMPREGNATION DATA SHEET

Negative: NC5a

Method: Chemical conversion

Conditions: 50% saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C

Number of cycles: 2

Plaque Data:

Size, cm^2 90.7 ; Thickness, cm 0.0780 ; Weight, g 14.5822

Density, g/cm^2 0.1607

Weight Gain, g:

1 1.0928	5	9
2 1.1290	6	10
3	7	11
4	8	12

Total Weight Gain, g 2.2218

Average weight of active material: 0.0245 g/cm^2 3.140 g/cm^3

Distribution of active material, g/cm^2: A 0.0259; B 0.0253; C 0.0356

Theoretical capacity (section A) 0.0095 A hr/cm^2; 0.123 A hr/cm^3

Measured capacity (section A) 0.0052 A hr/cm^2; 0.067 A hr/cm^3

Utilization factor, % 55

IMPREGNATION DATA SHEET

Negative: NC6a

Method: Chemical conversion

Conditions: 50% saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C

Number of cycles: 5

Plaque Data:

Size, cm^2 90.3 ; Thickness, cm 0.0816 ; Weight, g 15.1470

Density, g/cm^2 0.1677

Weight Gain, g:

1	1.1560	5	1.1593	9	
2	0.9649	6		10	
3	1.1947	7		11	
4	1.1695	8		12	

Total Weight Gain, g 5.6444

Average weight of active material: 0.0625 g/cm^2 0.7650 g/cm^3

Distribution of active material, g/cm^2

A 0.0584

B 0.0584

C 0.0583

Theoretical capacity (section A) 0.0228 A hr/cm^2; 0.279 A hr/cm^3

Measured capacity (section A) 0.0186 A hr/cm^2; 0.228 A hr/cm^3

Utilization factor, % 82

IMPREGNATION DATA SHEET

Negative: NC7a

Method: Chemical conversion

Conditions: 50% Saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C

Number of cycles: 8

Plaque Data:

Size, cm^2 90.3 ; Thickness, cm 0.0812 ; Weight, g 15.1821

Density, g/cm^2 0.1681

Weight Gain, g:

1 1.1273	5 1.1639	9
2 0.9761	6 1.0679	10
3 0.9310	7 1.0941	11
4 1.3418	8 0.9267	12

Total Weight Gain, g 8.6288

Average weight of active material: 0.0955 g/cm^2 1.1761 g/cm^3

Distribution of active material, g/cm^2

A 0.0984

B 0.0893

C 0.0960

Theoretical capacity (section A) 0.0360 A hr/cm^2; 0.444 A hr/cm^3

Measured capacity (section A) 0.0255 A hr/cm^2; 0.314 A hr/cm^3

Utilization factor, % 71

IMPREGNATION DATA SHEET

Negative: NC8a

Method: Chemical conversion

Conditions: 50% saturated $Cd(NO_3)_2$ + nitric acid, 25% KOH at 80 °C

Number of cycles: 12

Plaque Data:

Size, cm^2 90.3 ; Thickness, cm 0.0813 ; Weight, g 15.2077

Density, g/cm^2 0.1684

Weight Gain, g:

1	1.3928	5	1.3804	9	0.9500
2	1.2408	6	1.1958	10	0.8110
3	1.2439	7	1.1080	11	1.5390
4	1.2042	8	1.0044	12	

Total Weight Gain, g 13.0701

Average weight of active material: 0.1447 g/cm^2 1.780 g/cm^3

Distribution of active material, g/cm^2: A 0.1488; B 0.1371; C 0.1376

Theoretical capacity (section A) 0.0545 A hr/cm^2; 0.670 A hr/cm^3

Measured capacity (section A) 0.043 A hr/cm^2; 0.530 A hr/cm^3

Utilization factor, % 79